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ARCTIC AND SUBARCTIC ENVIRONMENTAL ANALYSES UTILIZING ERTS-1 IMAGERY

Principal Investigator
Duwayne M. Anderson (DE 329)

Co-Investigators

Harlan L. McKim
Richard K. Haugen
Lawrence W. Gatto
Charles W. Slaughter
Thomas L. Marlar

U. S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire 03755

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16. Abstract Physiognomic landscape features were used as geologic and vegetative indicators in preparation of a surficial geology, vegetation, and permafrost map at a scale of 1:1 million using ERTS-1 band 7 imagery. The detail available from ERTS-1 imagery at 1:1 million scale compared favorably with the detail available on U.S. Geological Survey Miscellaneous Geologic Investigation Maps at a scale of 1:250,000. Physical boundaries mapped from ERTS-1 imagery in combination with ground truth obtained from existing small scale maps and other sources resulted in improved and more detailed maps of permafrost terrain and vegetation for the same area. ERTS-1 imagery provides for the first time, a means of monitoring the following regional estuarine processes: daily and periodic surface water circulation patterns; changes in the relative sediment load of rivers discharging into the inlet; and, several local patterns not recognized before, such as a clockwise back eddy offshore from Clam Gulch and a counterclockwise current north of the Forelands. Comparison of ERTS-1 and Mariner imagery has revealed that the thermokarst depressions found on the Alaskan North Slope and polygonal patterns on the Yukon River Delta are possible analogs to some Martian terrain features.

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PREFACE

The purpose of this report is to discuss progress toward the following objectives: (1) mapping the permafrost areas of Alaska as inferred by vegetative patterns; (2) comparing major tonal and textural permafrost patterns with Mariner imagery; (3) analyzing and mapping sediment deposition in harbors, inlets and docking facilities in Cook Inlet; (4) correlating the snowpack cover of the Caribou-Poker Creek with stream runoff and inventorying icings on the Chena River.

The photointerpretation techniques used in analyzing the ERTS imagery have been similar for all portions of the investigation. Overlay maps were produced based on the variation of tones and textures visible in the imagery. The results were then compared with published maps and other sources of ground truth. Our ground truth activities have included under-flight and post-flight oblique aerial photography and ground-based measurements. Mapping and feature identification for the most part has been on the 1:1 million scale single band ERTS images. A few color composites, some of which were prepared in house, were utilized in vegetation mapping.

Surficial geology, vegetation, and permafrost terrain maps were produced for a 153,400 km^2 area in Alaska. These maps compare favorably with published information and in some instances considerable improvements were shown to have been made. The maps of surface circulation patterns, sediment and tidal flat distribution, coastal landforms and water boundaries in Cook Inlet illustrate regional estuarine processes. Large terrestrial thermokarst features evident on Mariner 9 imagery are being compared to Martian terrain features evident on

Mariner 9 imagery. It is considered likely that much of the rugged Martian topography was formed by processes characteristic of permafrost regions. A snow survey was made across the Caribou-Poker Creek watershed and stream runoff data was collected for late spring. An aerial reccnnaissance of icings in the Chena River was completed in March. These ground data are being correlated with ERTS imagery.

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1.0 Introduction

Initial findings for the first six months of this project, "Arctic and Subarctic Environmental Analyses Utilizing ERTS-1 Imagery" (GSFC ID DE-329, contract S-70253-AG), were reported in a Type II report submitted in December 1972. The findings presented in that report are summarized briefly as follows: ERTS images proved useful for the identification and interpretation of regional geology, hydrology, and geomorphic features. Eight surficial geology units were mapped on a color composite image (1003 - 21355) of the Kobuk and Koyukuk River valleys. With few exceptions the mapping compared favorably with available geology maps. Four vegetation units based primarily on tonal differences were mapped for the same area. These tonal differences were found to be primarily related to vegetation density and species composition. Five permafrost terrain units were also mapped based on the interpretation of surficial geology and probable depth of thaw inferred from the vegetative cover. Bands 5 and 7 were found to be the most useful for the analysis of coastal processes and sediment distribution in Cook Inlet, Alaska. Preliminary interpretations were made on two scenes that clearly show the sediment distribution and current directions along the west shore between MacArthur River and Squarehead Cove and in the central portion of the inlet around Kalgin Island.

Plans at the end of the first six month period were to extend the surficial geology, vegetation and permafrost terrain mapping to include larger areas and to map major sediment distribution and deposition patterns in the inlet, especially those near harbors and docking facilities.

On 29 June, 1973 a request for a six-month, no cost extension was submitted. This request was approved on 17 August, 1973. The basis for requesting an extension was explained briefly as follows:

1. Our project objectives require the mapping of permafrost areas of Alaska. Only partial completion of this objective has been possible because sufficient repetitive cloud and and snow-free coverage had been available for detailed mapping in North Central Alaska. Additional repetitive coverage was required to extend the preliminary vegetation and permafrost maps.

2. The first usuable imagery of Cook Inlet was acquired on November 3 and 4, 1972, and received in late December. Except for two images acquired in April and June, 1973, all subsequent imagery has contained at least 70 percent cloud cover. To verify preliminary interpretations of circulation and sediment distribution patterns seen in the November imagery additional coverage was required.

3. Definition of seasonal phenomena was not possible with the limited imagery available during the original contract period.

4. Thermokarst topography in the region of Yakutsk, Siberia and the thaw lake typography on the North Slope of Alaska were identified as possible analogs to some of the "chaotic" Martian terrain late in the contract period. ERTS imagery of these areas was not obtained until very late in this period and sufficient time for analysis therefore had not been available.

This second type II report sets forth technical progress and scientific results achieved during the period 24 December 1972 - 23 June 1973. To briefly recapitulate, the objectives of this investigation are:

* Analyze and map the sediment deposition in harbors, inlets, and docking facilities in the Cook Inlet.
* Map the permafrost areas of Alaska as inferred by vegetative patterns. Compare major tonal and textural permafrost patterns with Mariner imagery.
* Correlate the snowpack cover of Caribou-Poker Creek with stream runoff.
* Map and inventory the icing on the Chena River.

To test the feasibility of accomplishing detailed regional analyses, a 10-scene photo mosaic has been constructed of a 153,400-km^2 area in north-central Alaska. Surficial geology, vegetation and permafrost terrain units were mapped from this photo mosaic. Seven surficial geology units, eight vegetative cover units and four permafrost terrain units were defined and delineated. Permafrost units were mapped from textural and tonal patterns related to surficial geology and vegetation. Land and water features were identified on 13 ERTS scenes representative of major physiographic provinces throughout Alaska. Six MSS scenes were used to map surface circulation patterns, tidal flat configuration, suspended sediment distribution and water mass boundaries in Cook Inlet. Three ERTS scenes have shown major tonal and textural permafrost terrain patterns comparable to those seen on Mariner imagery; these include thermokarst depressions on the North Slope of Alaska and in the Yakutsk area of Siberia, patterned ground on the Yukon Delta.

Photointerpretation procedures followed during this period were similar for all phases of the work. Overlay maps based on tones and textures visible in the imagery were prepared. Stereo viewing was possible in some cases where image endlap and sidelap permitted and aided in interpretation where topography was a factor. Preliminary maps were based strictly on image interpretation. They were subsequently compared with published maps and other references. Operations to secure "ground truth" included under-flight and post-flight oblique aerial photography and particularly in the case of the marine studies, ground-based measurement. Most black and white mapping and feature identification was done directly from 1:1,000,000 prints or transparencies. Some color composites were utilized as they became available.

Imagery analysis was facilitated by several laboratory techniques and some specialized equipment. For example, from time to time it was necessary to prepare photographically enhanced reproductions and enlargements from the 70 mm or 9.5 in. bulk product positive transparencies. High contrast printing techniques were found to be necessary to bring out the information contained in the low contrast, low sun angle Alaska imagery. Tonal discriminations were facilitated by the use of a color densitometer, which was also used for planimetric measurements. A Bausch and Lomb Zoom Transferscope, which became available late in the study, was utilized in some of the mapping.

Reports prepared and presentations made during this reporting period are summarized in Table I. The state of the project and of the work planned for the next period is summarized in Table II.

TABLE I

Reports Prepared and Presentations Made During This Reporting Period

Reports Prepared

Report presented at the ERTS-1 Symposium by GSFC, 5-9 March 1973. "Sediment Distribution and Coastal Processes in Cook Inlet, Alaska" (attached).

Report presented at the Second Annual Remote Sensing of Earth Resources Conference, sponsored by the University of Tennessee Space Institute, 26-28 March 1973. "The Use of ERTS-1 Imagery in the Regional Interpretation of Geology, Vegetation, Permafrost Distribution and Estuarine Processes in Alaska" (attached).

Report published as CRREL Technical Report 241, June 1973. "An ERTS view of Alaska: Regional Analysis of Earth and Water Resources Based on Satellite Imagery".

Oral Presentations

Presentation given at the Dartmouth College Chapter of the Society of the Sigma Xi, 17 January 1973. "Satellite Technology at USACRREL".

Presentation given at the Dartmouth College Department of Earth Sciences meeting, 28 February 1973. "Arctic and Subarctic Environmental Analysis Utilizing ERTS-1 Imagery".

Presentation at the ERTS-1 Symposium sponsored by GSFC, 5-9 March 1973. "Sediment Distribution and Coastal Processes in Cook Inlet, Alaska".

Report presented at OCE, sponsored by Systems Analysis Branch, 9 March 1973. "Land Use and Pollution Patterns on the Great Lakes"; "Sediment Distribution and Coastal Processes in Cook Inlet, Alaska"; "The Utility of ERTS-1 Imagery in Mapping Geology, Vegetation and Permafrost Distribution in Alaska".

Presentation at the New England Junior Science and Humanities Symposium sponsored by the University of Massachusetts Department of Engineering, 5 April 1973. "The Use of ERTS-1 Imagery in the Analysis of Cold Regions Environments".

Presentation given at the Remote Sensing of Water Resources International Symposium in Burlington, Ontario, Canada, 11-14 June 1973. "The Use of ERTS-1 Imagery in the National Program for the Inspection of Dams".

TABLE II

Status Of Progress In The Investigation

Objective	Status	Work To Be Done	Products Available	Documentation
Analyze and map the sedi-deposition in harbors, inlets, and docking facilities in the Cook Inlet.	Imagery from 3 Aug 72 - June 73 has been analyzed - most useful imagery is from cycle 6 - Nov 72	Continue analysis of new imagery to confirm previous findings.	Maps of surface currents, suspended sediment and tidal flat distribution.	Report presented at ERTS-1 Symposium in March, 1973.
Map the permafrost areas of Alaska as inferred by vegetative patterns.	Imagery from cycle 3 & 4 of North Central Alaska was used to construct a mosaic for mapping - Mapping of this area is complete.	Continue mapping a new region.	Surficial geology, vegetation, and permafrost terrain maps.	Report presented at Second Annual Remote Sensing Symposium, March 1973, Univ. of Tenn. Space Institute.
Compare major tonal and and textural permafrost patterns with Mariner imagery.	Imagery of Alaskan North Slope, Yakutsk, Siberia, and the Yukon River delta have been acquired.	Analysis of imagery; comparison with Mariner imagery; computer processing at JPL.	Photo mosaics of North Slope and Alden River region near Yakutsk.	Report for Planetology Program, Principal Investigators Symposium at JPL (in preparation).
Correlate the snowpack cover of Caribou-Poker Creek with stream runoff.	Snow survey across watershed has been completed - runoff data collected.	Correlate the data with ERTS imagery.	Runoff data - Snow survey data; limited ERTS imagery.	
Map and inventory the icings on the Chena River.	Aerial survey completed - aircraft imagery acquired.	Compare ground and aircraft observations with ERTS imagery.	Aircraft Photography documentary icing occurrences.	

2.0 Identification and interpretation of selected geomorphic, vegetation and cultural features

Thirteen ERTS-1 MSS images have been examined in detail and annotated to provide interpretations of the various geomorphic and environmentally significant features occurring in representative physiographic provinces of Alaska. Most of the features noted are readily apparent in the illustrations to follow, but in a few cases the more subtle tones or textures of the feature of interest became obscured in the offset reproduction processes. In these cases, it may be necessary for the reader to consult a copy of the original photographic reproduction of the scene to fully verify the interpretation provided here. High quality reproductions of all imagery used in this report are available at nominal cost from the EROS Data Center, Sioux Falls, S.D., or they may be viewed at the ERTS browse room at the Goddard Space Flight Center or at USACRREL.

Shown in Figure 1 is the northern coast of Alaska, including Prudhoe Bay (1). An open ice edge (2) separates a shore lead (3) from close pack ice (4), and numerous oriented thaw lakes (5) dot the arctic coastal plain.* Jones Island (6) and the Colville Delta (7) are north of the coastline. Clouds cover 60% of the scene.

Sea ice is shown in figure 2; over 95% is a close pack ice (1). In the pack may be seen such features as polynyas (2), pressure ridges

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* Circled numbers on all imagery in this report indicate that an area is being referred to; arrows indicate specific features.

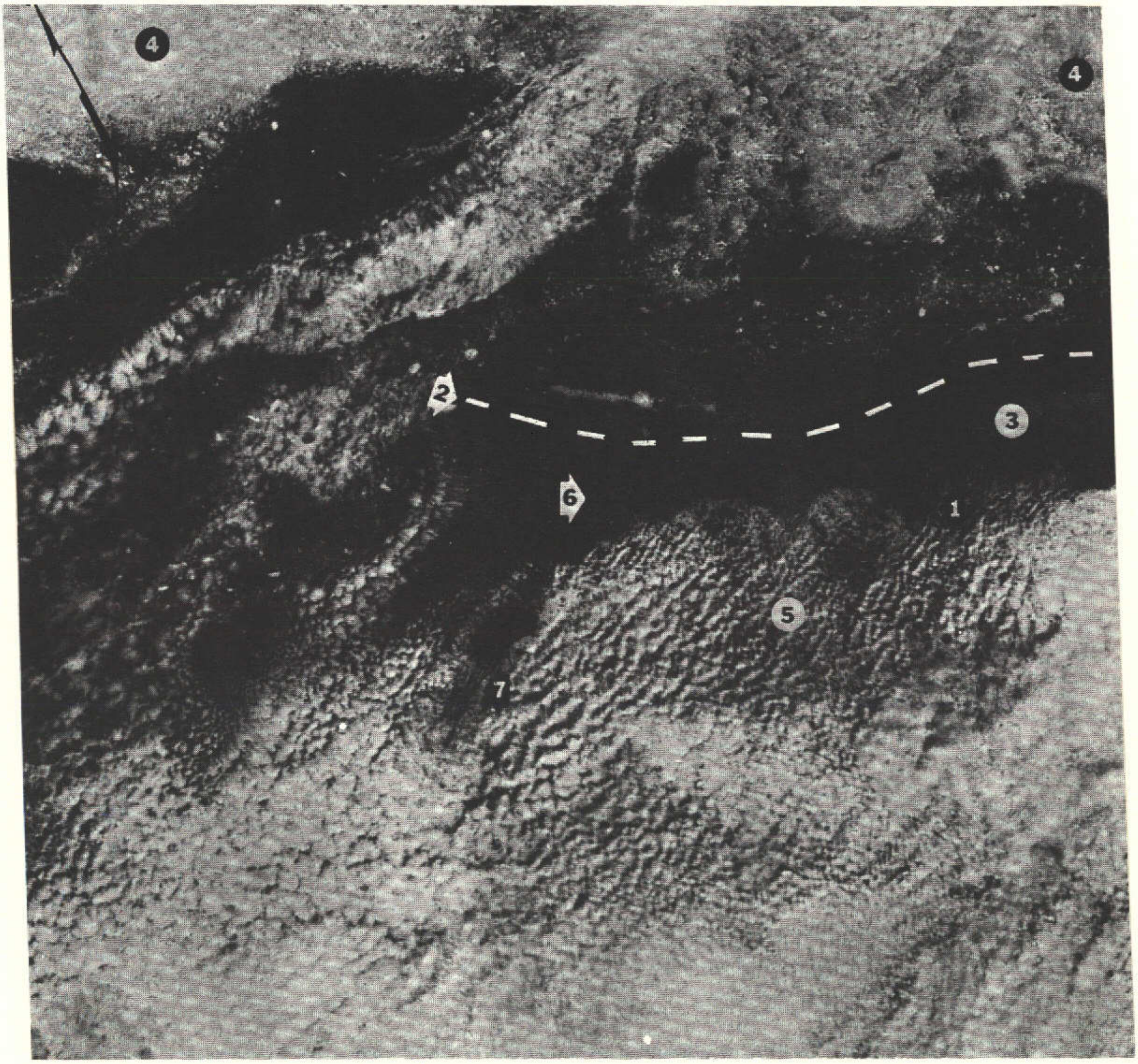


Figure 1. Coastal area on the North Slope of Alaska near Prudhoe Bay. MSS Band 7, image 1020-21281.

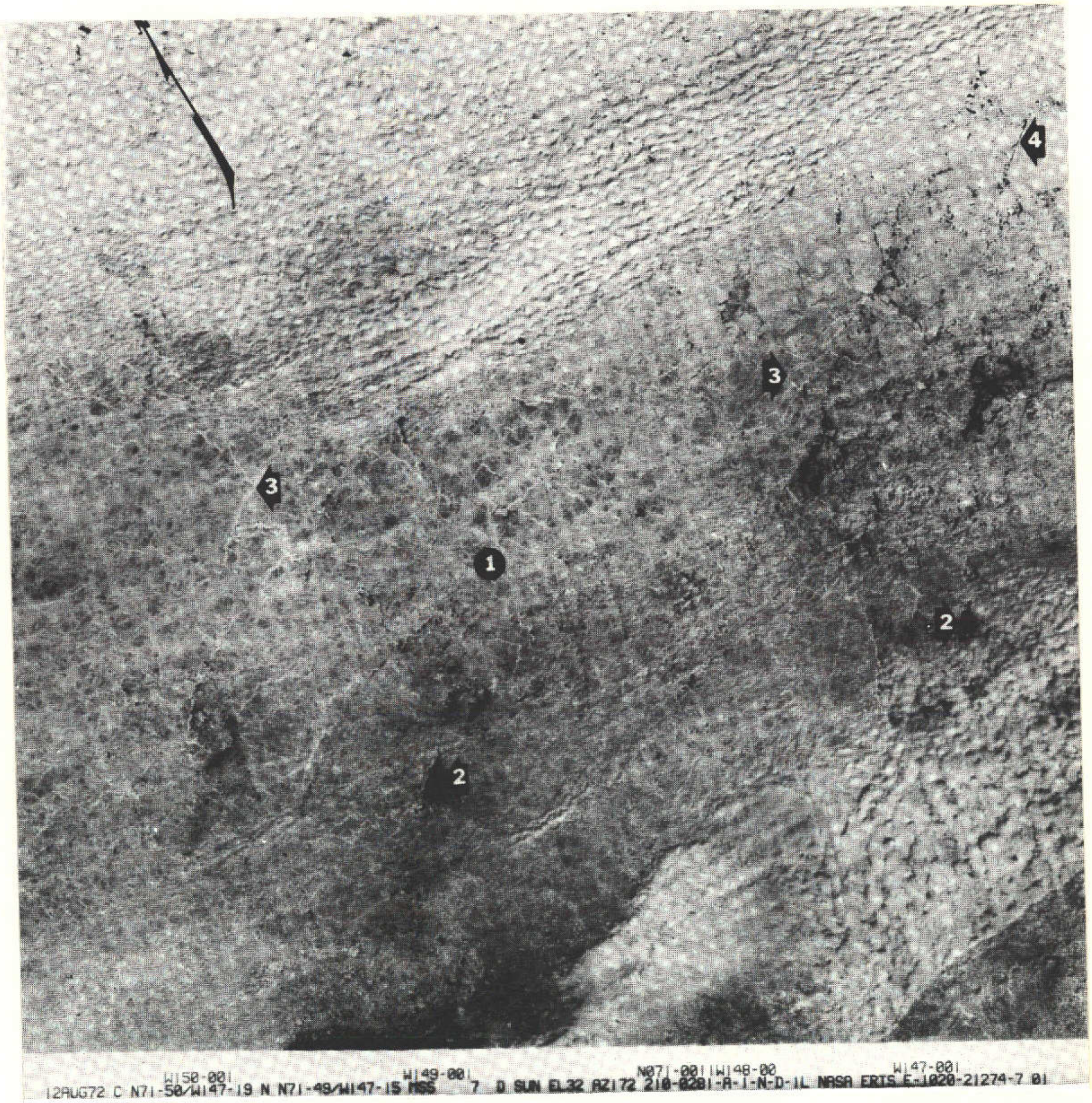


Figure 2. Sea ice north of Prudhoe Bay. MSS Band 7, image 1020-21274.

(3) and leads (4). The variation in gray tones is related primarily to ice thickness. The black tone is indicative of open water; the dark gray tones indicate thin ice and the lighter gray tones thick ice. Clouds obscure the pack in the northwest and southeast corners of the image.

Figure 3 is an image of the Norton Sound area. The Kigluaik Mountains (1), composed primarily of Paleozoic metamorphic rocks (Dutro and Payne, 1954), are a prominent feature. An open ice pack (2) with many polynyas (3) covers Norton Sound in this winter scene. The fast ice boundary is easily located (4); fast ice (5) occurs along the coast and is seen to extend seaward to Sledge Island (6). The Sinuk River (9) enters and flows under the fast ice. Grease ice (10) can be observed south of Rocky Point (11) and Golovnin Bay (12). Port Safety (7) and Nome (8) are icebound in this image.

The Yukon River Delta (1) on the western coast of Alaska projects into the Bering Sea (Fig. 4). Fast ice (2) extends 3 to 7 miles seaward. New ice (3) occurs along the fast ice boundary (4). Grease ice (5) covers a major portion of the area between the fast ice boundary and open ice pack (6). The open pack ice in the Bering Sea contains ice fragments varying in dimension from tens to hundreds of meters.

Vegetation associations were annotated in an image of the Holy Cross (8) area along the Yukon River (9) (figure 5). Ground truth for the interpretation of vegetation patterns was obtained from field notes and the Alaskan vegetation maps by Spetzman (1963) and Viereck (1972); seven associations are recognizable. Wet tundra (1) is

Figure 3. Sea ice in Norton Sound. MSS Band 7, image 1205-21595.

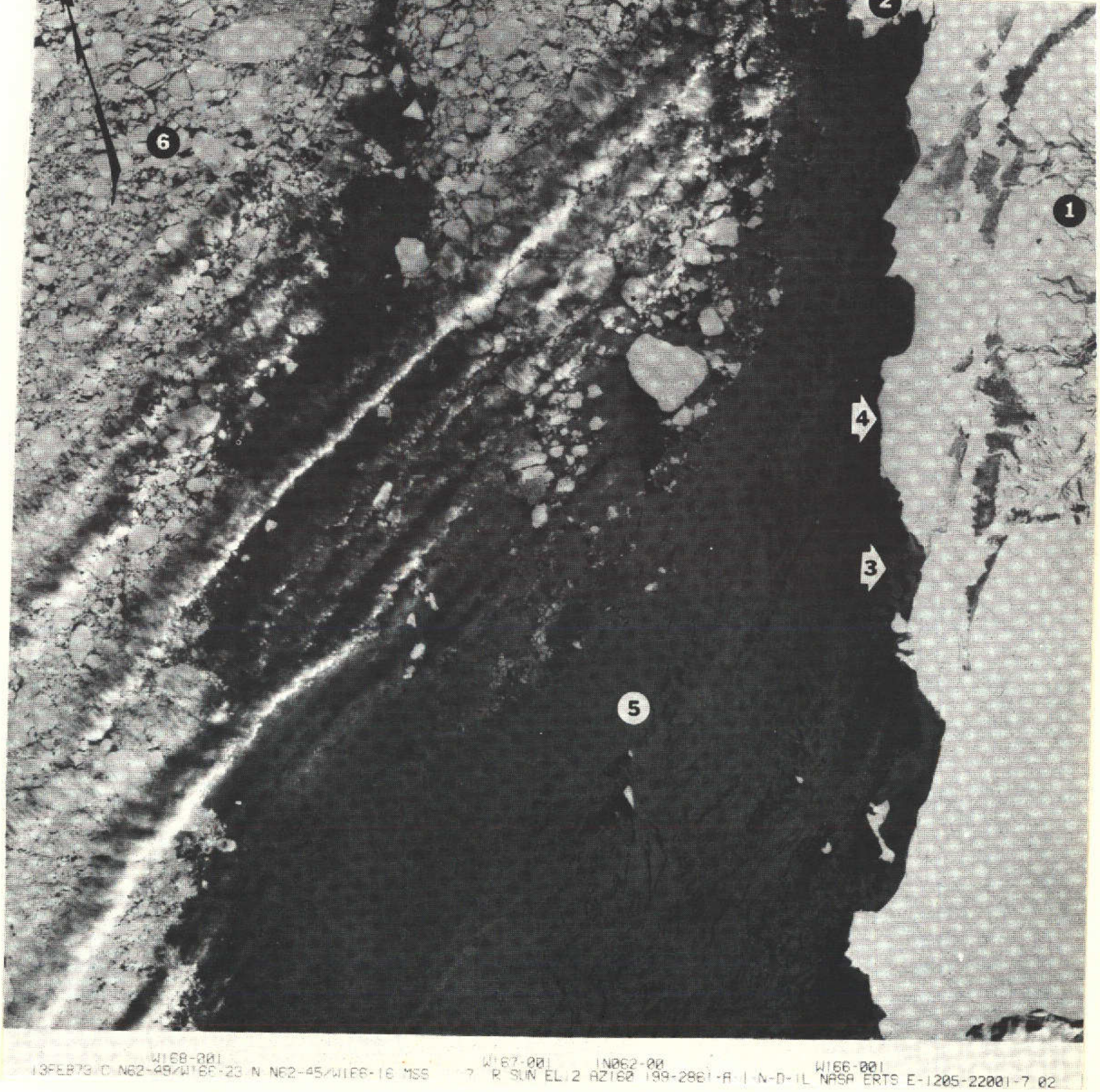


Figure 4. Sea ice in the Bering Sea near the Yukon River Delta. MSS Band 7, image 1205-22001.

Figure 5. Vegetation distribution along the Yukon River in the Innoku Lowlands. MSS Band 5, image 1002-21324.

characterized by sedges, grasses and aquatic plants 0.3-0.6 m high with higher willow brush along stream banks. Many thaw lakes and thermokarst depressions are present. The depth of seasonal thaw over the continuous permafrost is shallow in this lowland area. Thaw lakes (2) appear both as light and dark tones indicating varying amounts of water turbidity. Several lakes are similar in tone to the sediment-laden Yukon River; other lakes are dark with some evidence of surface patterns. The effects of wind and water depth are largely responsible for the variable tones of many of these lakes. Moist tundra (3) is characterized by cottongrass tussocks associated with mosses, lichens, low heath shrubs and higher willows along stream banks. Tussocks are interspersed with stunted trees near forest margins. The moist tundra area is gently sloping and also has a shallow seasonal thaw depth. Upland white spruce, birch, and aspen forest (4) is intermixed with moist tundra in the valleys (lighter tones). Depth to permafrost in this association is deep on south-facing slopes but shallow in the valleys. Sloughs and small lakes with aquatic vegetation are located in the closed white and black spruce forest mixed with high brush (5). This forest occurs on active floodplains usually composed of unfrozen alluvial materials. Closed white and black spruce forest (6) occurs mainly on well-drained slopes and in hilly areas grades to alpine tundra at elevations over 300 m. Open black spruce forest (7) is mixed with birch, aspen, poplar and willow. The undercover plants are shrubs and the ground cover is cottongrass tussocks, mosses and lichens. Dense spruce-deciduous forest (10) and high brush border the Kuskokwim River.

The Ahklun Mountains (1) and the surrounding mountains in figure 6

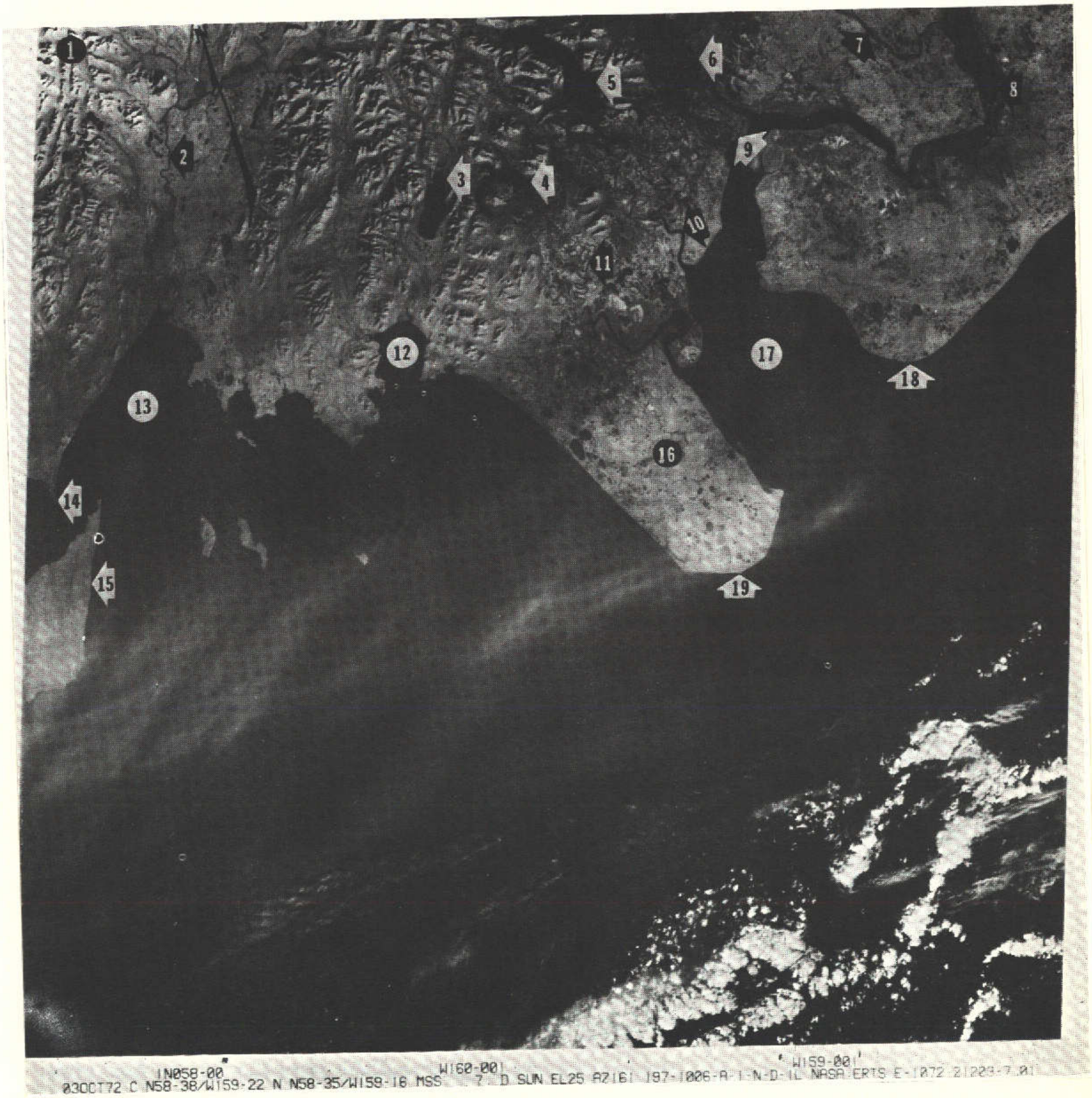


Figure 6. Nushagak Peninsula and the Dillingham area on the northern coast of Bristol Bay. MSS Band 7, image 1072-21203.

are composed predominantly of undifferentiated marine and nonmarine rocks of Lower Cretaceous, Jurassic and Triassic age. The lowlands, marked with numerous lakes, are predominantly undifferentiated Quaternary glacial and glaciofluvial deposits (Dutro and Payne, 1954). The Togiak River (2) follows the western portion of the Denali fault zone which extends into Togiak Bay (13). Ualik (3), Amanka (4) and Nunavaugaluk (5) Lakes occupy abandoned glacial valleys. The entire area was extensively glaciated from early to late Pleistocene. The late Pleistocene glaciers terminated south and east of these lakes (Coulter et al., 1962). Wood River (6) originates in Lake Aleknagik, partially shown on the north side of the image. The Iowithla (7) and Nushagak (8) Rivers drain a large glacial floodplain. Well-defined meanders and oxbows occur along the Nushagak River. The flood tides in Bristol Bay inundate the lower portion of this river; the point where the meanders abruptly terminate marks the upstream limit of these tidal waters. Dillingham (9) is located on Nushagak Bay (17). Rapid siltation in Dillingham harbor has caused it to be occasionally unusable during the low tide cycle (Corps of Engineers, 1971). The high sediment concentration in the bay is contributed by the silt-laden Iowithla, Nushagak, Wood, Snake (10) and Igushik (11) Rivers. The Snake and Igushik Rivers originate in the glacial valleys and lakes to the north. Kulukak (12) and Togiak (13) Bays mark areas where middle to late Pleistocene glaciers extended seaward of present land areas. The locations of their termini are marked by submarine features (Coulter et al., 1962) which are not visible on this image. Tongue Point (14) is a well-developed spit indicating a local westwardly current between the mainland and Hagemeister Island (15). The linear southeast coast of the island marks the offshore location of the Denali fault zone (Dutro and Payne, 1954). Nushagak Peninsula (16) is composed of Quaternary glacial deposits and is marked by arcuate terminal moraines (lighter in tone) of middle to late Pleistocene glaciers. The spits on the lower east shore of the peninsula indicate a predominant northward current in this area. Extensive tidal flats are visible along the shore of Nushagak Bay (17). Etolin Point (18) and Cape Constantine (19) mark the entrance to the bay.

Figure 7 includes Seward (1), located at the head of Resurrection Bay (2) in Blying Sound (3) on the north shore of the Gulf of Alaska. The area is in the rugged and extensively glaciated Kenai Mountains. Harding Icefield (4) has numerous valley glaciers, including Bear (5), Aialik (6), Holgate (7) and McCarty (8) Glaciers, which terminate in the local fiords. The medial moraine in Bear Glacier is well defined. North of Seward, Kenai Lake (9) occupies one of many abandoned glacial valleys (10) in this area. Northeast of Seward, the Ellsworth (11) and Excelsior (12) Glaciers have proglacial lakes at their termini. Prince William Sound (13) and Montague Island (14) are located in the eastern portion of the scene. Altocumulus clouds (15) may be seen in the southeast portion.

In Figure 8, Valdez (1) is located at the head of Valdez Arm (2) in the northern part of Prince William Sound (3). It is surrounded by the glaciated Chugach Mountains (4). The multitude of valley glaciers and abandoned glacial valleys (5) illustrates the extensive glaciation of this area. Columbia (6), Yale (7) and Harvard (8)

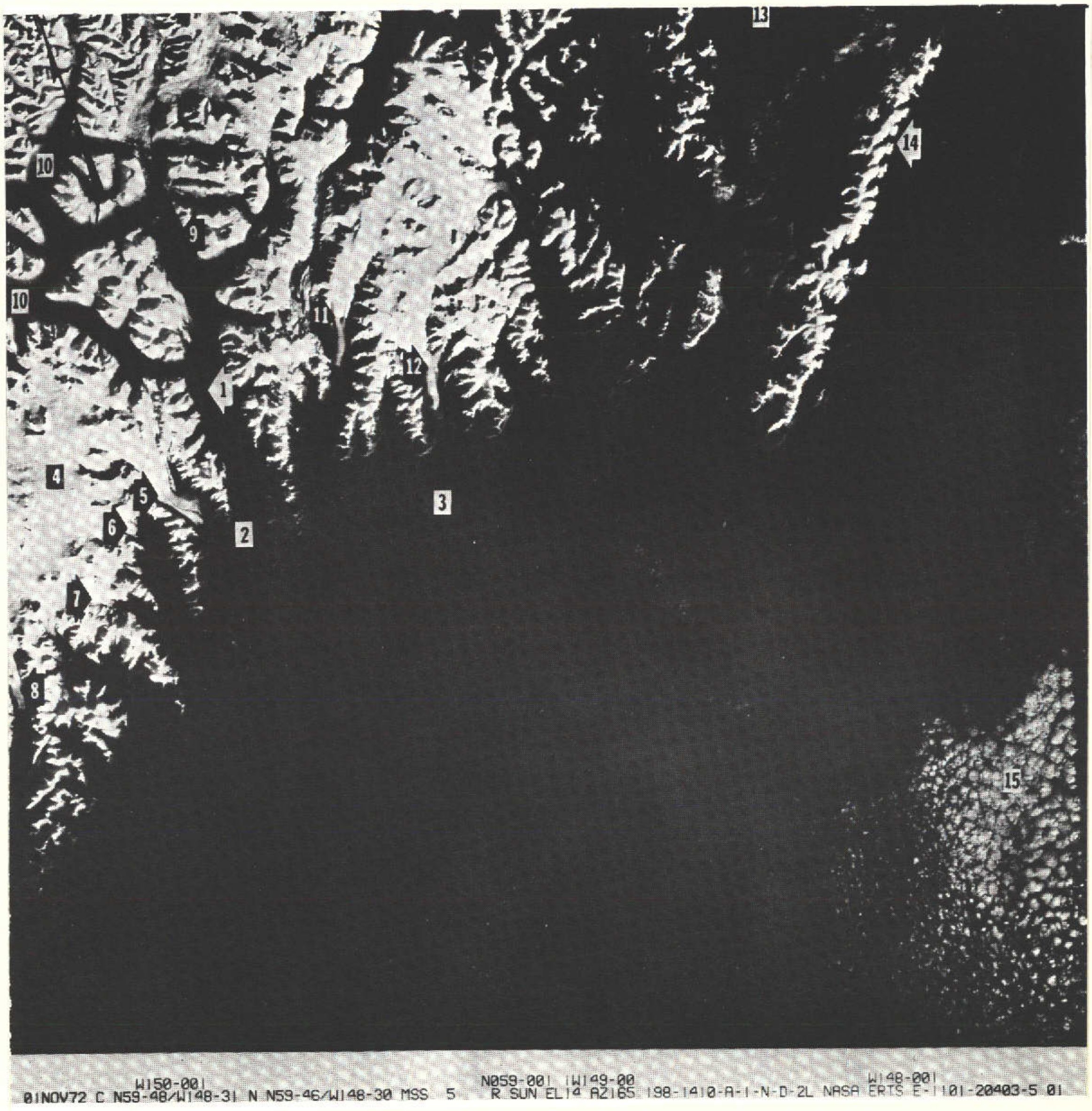


Figure 7. The Seward area of south-central Alaska. MSS Band 6, image 1101-20403.

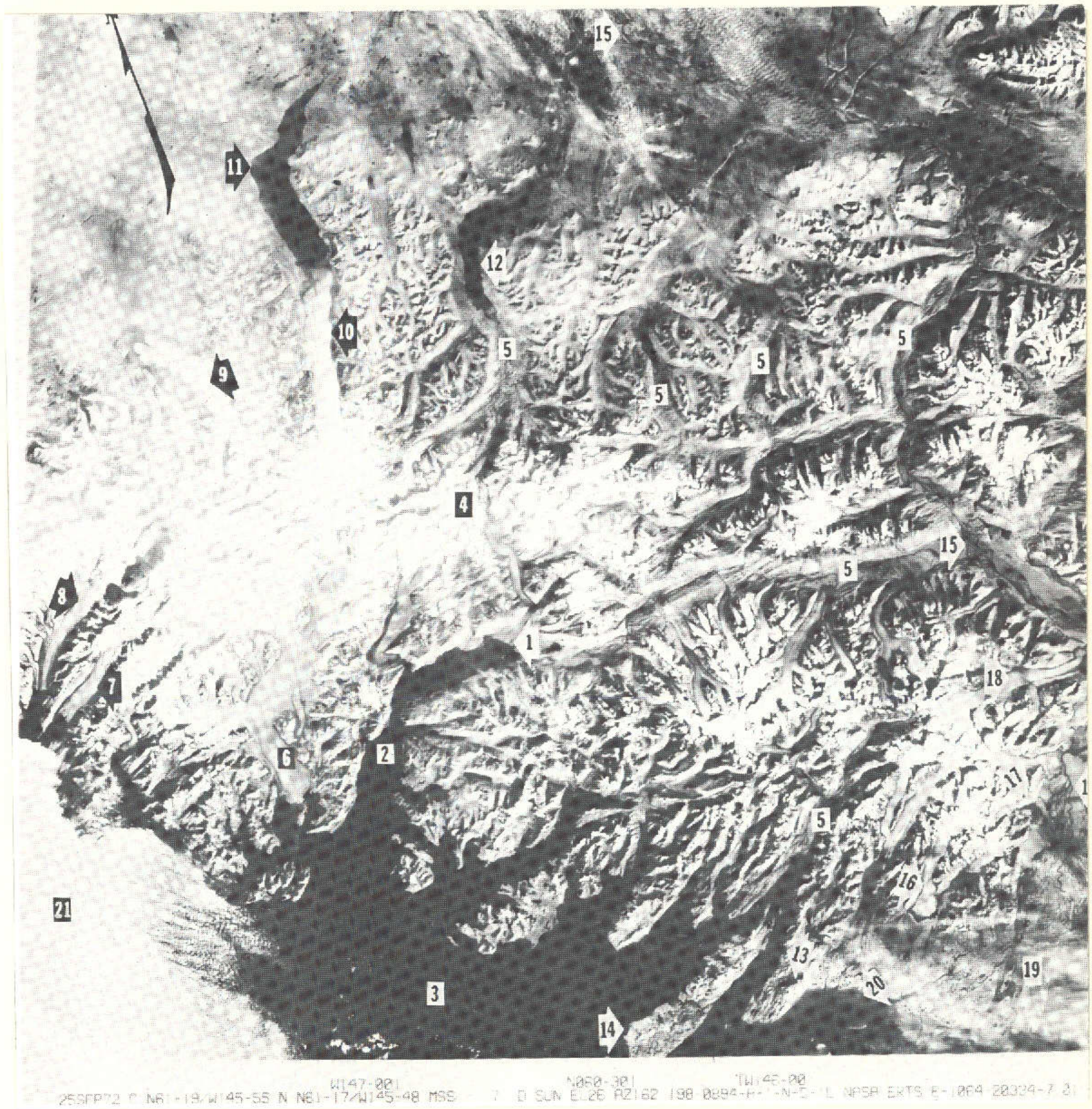


Figure 8. The Valdez area along the northern coast of Prince William Sound. MSS Band 7, image 1064-20334.

Glaciers with their well-defined lateral and medial moraines terminate in the fiords west of Valdez. Many of the glacier surfaces are covered with snow in the higher elevations and the snowline, an important climatic indicator, is quite distinct. At the terminus of Columbia Glacier is a concentration of floating glacial ice which calved from the glacier. Nelchina (9) and Tazlina (10) Glaciers flow northward into the flatlands and Tazlina Lake (11), respectively. Klutina Lake (12) is in an abandoned glacial valley of the Klutina Glacier which extended farther down the valley in the past. Cordova (13) is located on the mainland east of Hawkins Island (14). The Chugach Mountains north of this town have many piedmont glaciers which terminate in the Copper River (15) lowland. Examples are the Sheridan (16), Childs (17), and Allen (18) Glaciers. The high concentration of glacial sediment in the Copper River is deposited in the Gulf of Alaska and has formed a large delta (19). Sediment deposited in the near-shore areas form tidal flats (20). Altocumulus clouds (21) obscure the northwest portion of Prince William Sound.

Malaspina Glacier (1), a large (approximately 75 km wide) piedmont glacier fed by numerous valley glaciers originating in the Saint Elias Mountains, dominates the scene shown in figure 9. The snow covering of the glacier enhances and makes visible its surface topography. The rugged topography of the stagnant area and the thrust moraines at the terminus are discernible. Braided streams and proglacial lakes border the glacier terminus. Yahtse (2), Columbus (4) and Seward (5) Glaciers are valley glaciers flowing from or forming part of the Bagley Icefield (3) in the Chugach and Saint Elias

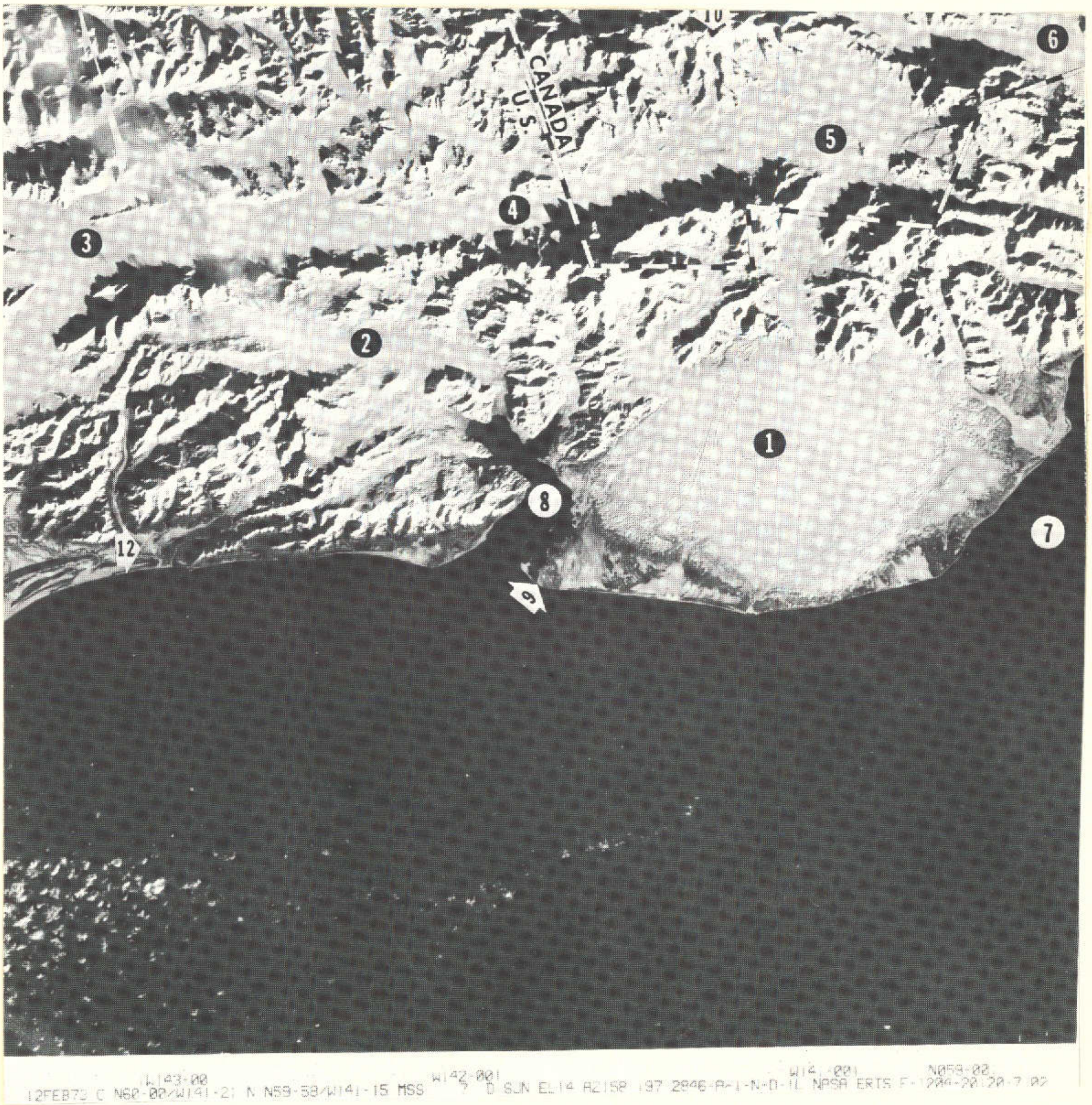


Figure 9. Malaspina glacier in southern Alaska. MSS Band 7, image 1204-20120.

Mountains. There is a high concentration of suspended sediment near the terminus of Yahtse Glacier and in Icy Bay (8). Hubbard Glacier (6), a large glacier in the St. Elias Mountains, drains into Disenchantment Bay (not on frame) at the northern end of Yakutat Bay (7). Mt. Logan (6050 m) (10) and Mt. King George (3750 m) (11) are two of the highest peaks in the St. Elias Mountains. North of Point Riou (9) is a clearly defined spit-like feature which may be a reef formed from an old terminal moraine of the Malaspina Glacier. The Duktoth River (12) drains a portion of the Robinson Mountains located west of Icy Bay (8). The area around the river mouth is a portion of the glacial floodplain of the Bering Glacier (to the left of this scene).

The eastern extension of the Denali fault zone through the highly glaciated Saint Elias Mountains of southeastern Alaska and northern Canada is seen in figure 10. The Denali fault is a major structural feature of Alaska arcing across the state from the northern coast of Bristol Bay to the international border between the United States and Canada. The White River (1) flows through extensive glacial deposits of late Pleistocene age near the border (Dutro and Payne, 1954). This river originates from glaciers in the Wrangell Mountains and is also fed by meltwaters from Klutlan Glacier (5) in the northern St. Elias Mountains. Meltwaters from Donjek Glacier (6) and Kluane Glacier (7) form the head of the Donjek River (2) which flows north across the Denali fault zone and joins the White River. The Kluane

Figure 10. The Denali fault zone and major glaciers in the St. Elias Mountains of southeastern Alaska. MSS Band 5, image 1204-20114.

River (3) flows from Kluane Lake (4) through glacial and glaciofluvial deposits in an abandoned glacial valley. A thin cloud haze obscures the western end of Kaskawulsh Glacier (8), a large valley glacier that drains into Kluane Lake and forms the Kaskawulsh River. Hawkins Glacier (9), Barnard Glacier (10), Anderson Glacier (11), Chitina Glacier (12), and Logan Glacier (13) are valley glaciers which terminate in the Chitina River valley. Meltwater from them forms the Chitina River.

Vegetation associations were identified in Figure 11. Minto Flats (1), west of Fairbanks (17), is covered by low brush muskeg interspersed with stunted black spruce, birch and aspen that border the numerous small thaw lakes and meandering stream courses. Thick ground cover includes sedges and mosses. Floating mats of aquatic vegetation are found on many of the lakes. Permafrost usually occurs near the surface except in the immediate vicinity of larger lakes and active stream courses. The extensive flat area south of Fairbanks is locally known as the Bombing Range. Vegetation in this area is primarily low brush muskeg, with linear developments of black spruce, birch and aspen. (The linearity is caused by locally better drained areas near active or abandoned stream courses.) Wood River Buttes (2), Blair Lake Buttes (3) and Clear Creek Buttes (4) are well-drained and have a well-developed mixed spruce, aspen and birch forest. Continuous permafrost occurs under a shallow seasonal thaw zone throughout the area except for the well-drained buttes and areas adjacent to large streams or lakes where it is absent.

Figure 11. Fairbanks and the Yukon-Tanana Uplands. MSS Band 7, image 1102-20560.

Closely spaced white spruce forest (16) covers most of the moderately to well-drained upland portions of this scene. The timberline ranges from 750 m in the western part of the scene to about 1000 m in the eastern part. The alpine tundra appears white due to snow cover. This tundra association grades from willows and alders 2 1/2 - 4 m high near the timberline to dwarf willows and alders, herbs, and lichens at higher elevations. The alpine zone is barren above about 1200 m. Wickersham (5), Murphy (6) and Livengood (9) Domes are identified. Eielson AFB (7) and Fairbanks International Airport (8) are also observable. The Yukon River and Rampart Canyon (11) are located in the northwest corner of the image. Manley Hot Springs (12) to the south of Sawtooth Mountain (19) is included in this scene. Evidence of gold dredging can be seen in the Goldstream valley near Fox (13) and at Ester Creek (14). The "tailings" left by the dredges cover the floodplains of streams and, for the most part, are unvegetated and highly reflective. Permafrost is absent in these areas. Extensive tailing piles near Chatanika (15), however, have been overgrown with vegetation and are distinguishable only on very close examination.

In Figure 12 the Chena (1), Salcha (2) and Goodpaster (3) Rivers head in the Yukon-Tanana Uplands and drain a large portion of this province. The Tanana River (4) and its tributaries drain a major portion of east-central Alaska. The river itself is a major tributary to the Yukon River. The road networks and development patterns

Figure 12. Junction of the Tanana and Delta Rivers. MSS Band 5, image 1029-20383.

of the Delta Junction and Fort Greely area (5) are distinct at the confluence of the Delta River (6) and the Tanana. The Alaska Highway (7) crosses the entire frame. Vegetative patterns are annotated in this area. Alpine tundra (10) is present on Donnelly Dome (8) and other high elevations. The alpine tundra consists of low flowering plants, lichens, willow, alder, and birch 3-4 m high near the timberline with low dwarf varieties at upper elevations. This area is generally underlain by permafrost except on some steep south-facing slopes. Vegetation grades to barren ground at upper elevations. White spruce forests (9) consist of closely spaced white spruce mixed with birch and aspen on moderately to well-drained sites. The ground cover consists of alder and willow shrubs, grasses, herbs and mosses. Permafrost is scattered or absent on south-facing slopes, along large stream courses and in well-drained outwash plains. Cottongrass is the dominant plant in the moist tundra (11). Willow and alder shrubs occur at lower elevations and grade to open black spruce forest in lowlands; permafrost is near the surface. The Shaw Creek Flats (12) is a wet, treeless, boggy area with willow, alder, and dwarf birch 1-1 1/2 m high. Ground cover consists of cottongrass tussocks and sphagnum moss. The ground cover grades to widely spaced black spruce around the margins. The seasonally thawed layer is shallow. Areas of open black spruce forest (13), mixed with birch and aspen, cover much of the moderately well-drained lowland portions of the Tanana valley. The vegetation grades into high closed spruce forest near the streams where permafrost may be absent, and changes to moist tundra toward the foothills of the Alaska Range. The ground cover consists of shrubs, cottongrass tussocks and mosses and the permafrost table is at shallow depth. Areas covered by shrubs and muskeg (14) are similar to the Shaw Creek Flats area.

The Alaska-Canada border (1) crosses the eastern part of Figure 13 although the cleared swath marking the border is not visible because of the lack of contrast between the cleared, but vegetated, area and the forested surroundings. In the Yukon Territory (2), the Yukon River (3) and the Sixtymile River (4) are easily identified. In the Yukon-Tanana Uplands, the alpine zone of Mt. Fairplay (5), portions of the Taylor Highway, a gravel road (6), the Alaska Highway (8), and the Tanana River and floodplain (7) are clearly visible. The town and airport at Tok (9) are adjacent to the Alaska highway. Some of the highest peaks (>1800 m) (10) occur in the northwest corner of the scene. Glacier Mountain (11) is located in another group of high peaks to the east. Although the uplands have not been extensively modified by continental glaciation, local valley glaciers have eroded cirques in the highest peaks (10 and 11). These glacial features contrast with the sharply incised ridges and V-shaped valleys (12) of the lower, unglaciated portions of the uplands. Although this area abounds with geomorphic features characteristically associated with permafrost, such as solifluction terraces etc., these forms are not clearly distinguishable. Numerous pingos varying from 3 to 30 m high and from 8 to 360 m in diameter are known to be present in this area. Many pingos have been identified in the area (13)

Figure 13. Yukon-Tanana uplands, Canadian border. MSS Band 5, image 1081-20272.

along the Ladue River (14). An area (15) near Prindle Volcano (16) also contains many pingos which are easily identified from aerial photography. Still others have been observed in the Mt. Fairplay (5) and Mosquito Flats (17) areas. The regional vegetation here consists of three major associations: alpine tundra, closed mixed spruce-hardwood forest in the uplands, and brush-muskeg thickets in the lowlands. The white spruce timberline reaches an elevation of about 1200 m in the vicinity of the Canadian border.

3.0 Regional physical analysis

The first usuable ERTS-1 images for our investigation were obtained during orbit 30 on 25 July 1972. Since then more than 5000 scenes have been received and reviewed. Those images that are relatively cloud-free and taken at favorable sun elevations were selected and have been subjected to interpretation and study.

3.1 Surficial geology

The surficial geology of a 153,400 km^2 area in north-central Alaska was mapped on a 1:1 million scale uncontrolled photo mosaic (Fig. 14) with the aid of stereo pairs. Seven recognizable units have been defined (Fig. 15). Bedrock (b) consists of in-situ bedrock and very coarse, rubbly bedrock colluvium primarily confined to steep slopes and mountain crestlines. Bedrock-colluvium (bc) is composed of coarse- to fine-grained deposits occurring on moderate to steep slopes in mountainous terrain and rolling uplands which have minor

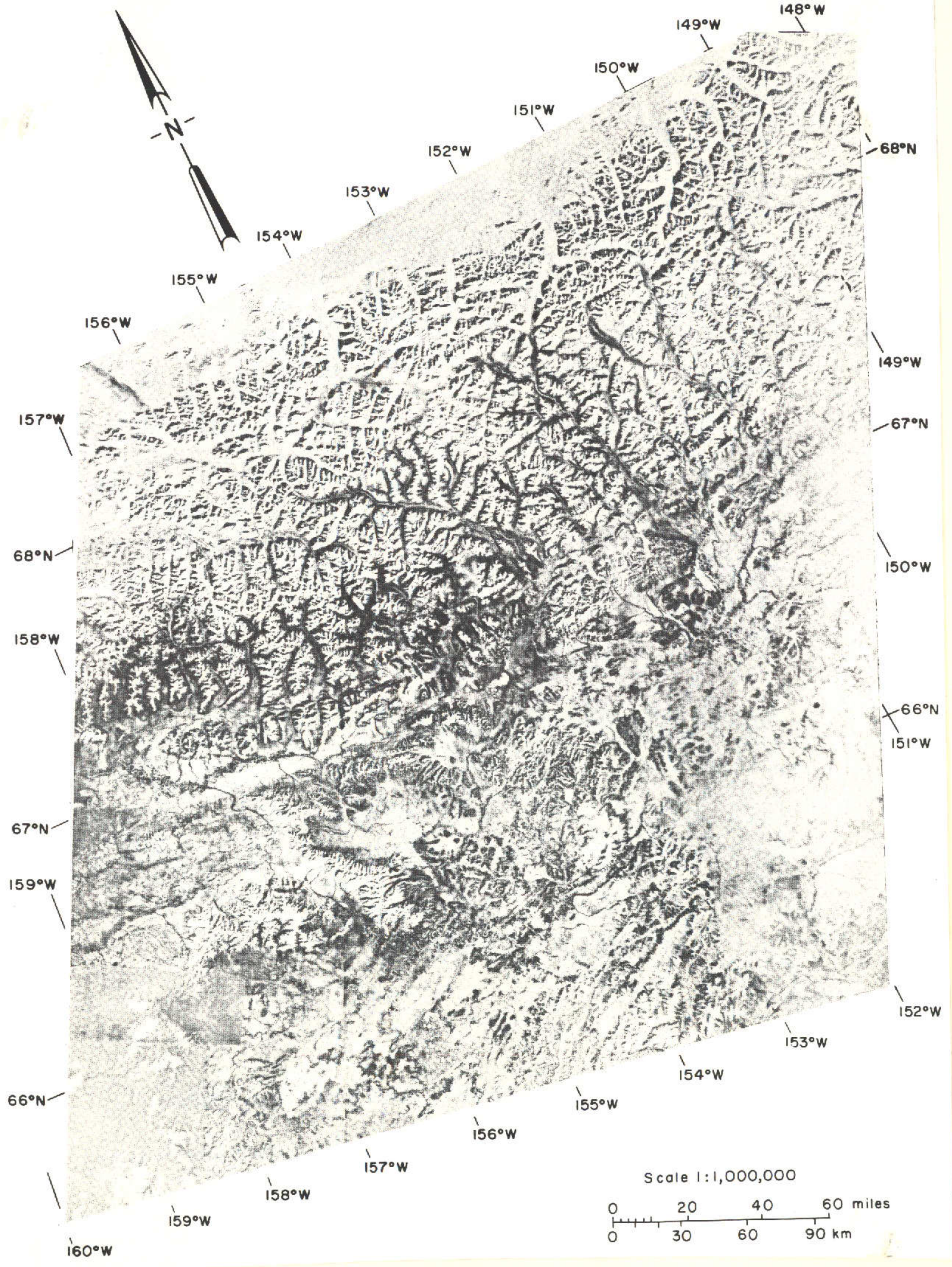


Figure 14. Uncontrolled photo mosaic of 153,400-km^2 area in north-central Alaska.

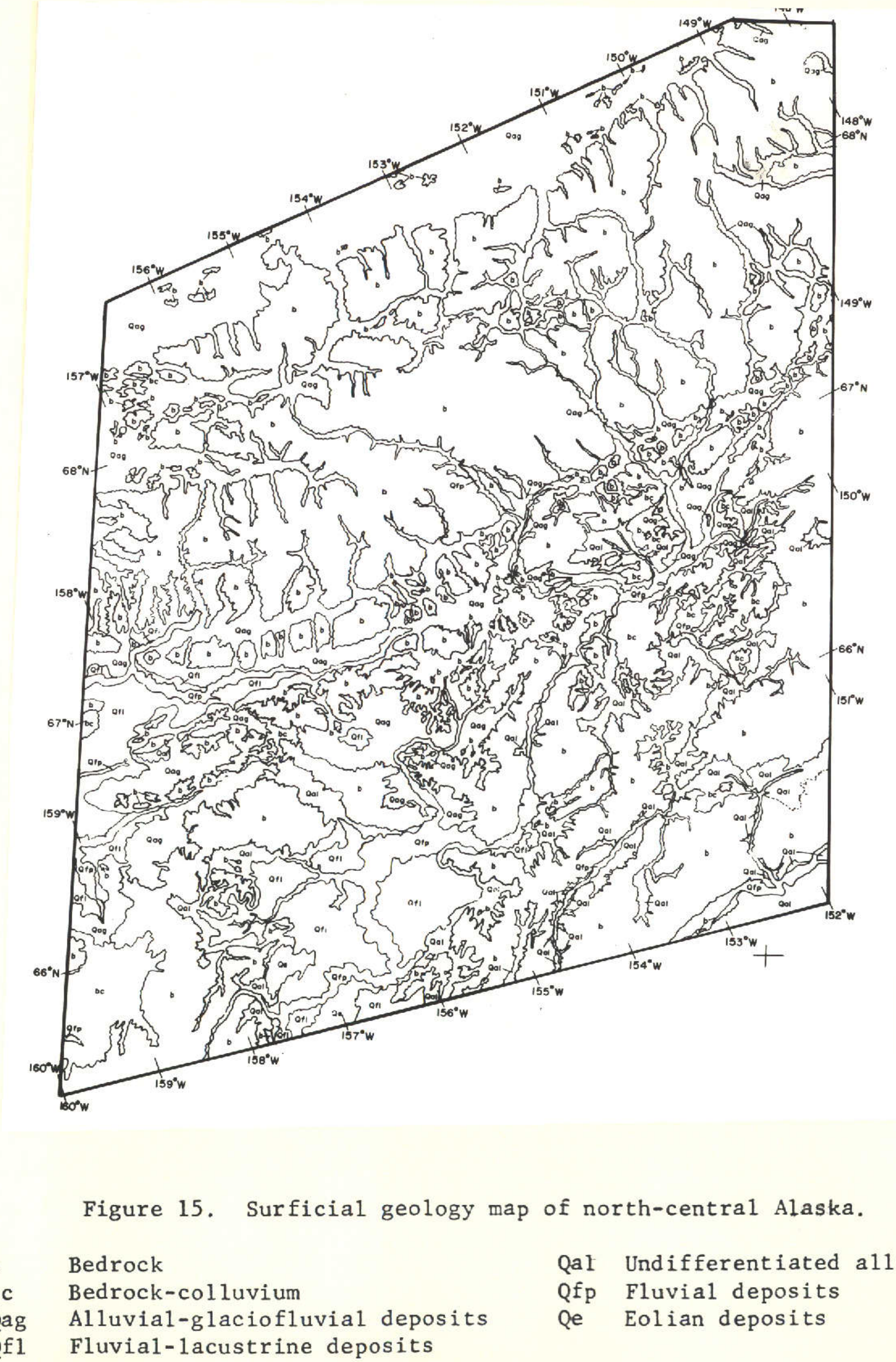


Figure 15. Surficial geology map of north-central Alaska.

b	Bedrock	Qal	Undifferentiated alluvial deposits
bc	Bedrock-colluvium	Qfp	Fluvial deposits
Qag	Alluvial-glaciofluvial deposits	Qe	Eolian deposits
Qfl	Fluvial-lacustrine deposits		

scattered bedrock exposures which are restricted to the uppermost slopes and crestlines. Alluvial-glaciofluvial deposits (Qag) are fine- to coarse-grained sediments derived from reworked glacial and alluvial deposits, morainal deposits, till, and outwash gravels and sands. These deposits occur in part on modified morainal topography and large alluvial terraces. Fluvial-lacustrine deposits (Qfl) consist of fine-grained sands and silts associated with abandoned floodplains and low-lying terraces. They may include windblown sand and silts. Undifferentiated alluvial deposits (Qal) are fine- and medium-grained alluvial fan, terrace, stream and eolian deposits. Fluvial deposits (Qfp) are fine- and medium-grained silts and sands, generally well rounded, associated with modern floodplains and low-lying terraces. Eolian deposits (Qe) are fine-grained windblown sediments, deposited on gently to moderately sloping hills and low-lying flatlands and include some areas of actively drifting dunes.

The units selected and defined for mapping the surficial geology of this area were subsequently compared to available USGS Miscellaneous Geologic Investigations Maps (Cass, 1959; Patton, 1966; Patton and Miller, 1966; Patton et al., 1966; Webber and Péwé, 1970) at a scale of 1:250,000 and the 1:1.5 million scale Surficial Geology of Alaska map (Karlstrom et al., 1964). The comparisons established that the map resulting from this investigation correlates favorably with the published 1:250,000 maps and is superior to the 1:1.5 million map.

3.2 Vegetation

Vegetation differences appear on the MSS imagery primarily through tonal rather than textural patterns. The tonal differences seem to be clearly related to both vegetation density and species composition. Eight plant associations and density levels have been identified, defined and mapped (Fig. 16).

Tall to moderately tall, closely spaced spruce-hardwood forest (Fc) consists of white and black spruce with paper birch, aspen, and balsam poplar on moderately to well-drained sites such as active floodplains, mountain slopes (especially southern slopes) and highland areas. The second plant association (Fou) has basically the same species as the close spaced spruce-hardwood forest (Fc) except that the vegetative cover appears less dense. Also the Fou unit has an ecological setting similar to Fc but it extends to somewhat less favorable habitats. Open black spruce forest (Fo) has stunted, open tree growth which includes tamarack, white birch and white spruce in addition to the dominant black spruce. Thick moss, grasses and heath comprise the ground cover. Open black and white spruce forest (Fod) is confined to several isolated areas where the forest has overgrown and stabilized sand dunes. This forest tends to be open, but is better drained and not as stunted as within the Fo class. Moist tundra (Tm) occupies vast areas of poorly to moderately drained topography. It contains some stunted black spruce within the southern two thirds of the study area. Cottongrass tussocks are the dominant vegetation form, with sedges and dwarf shrubs where tussocks are

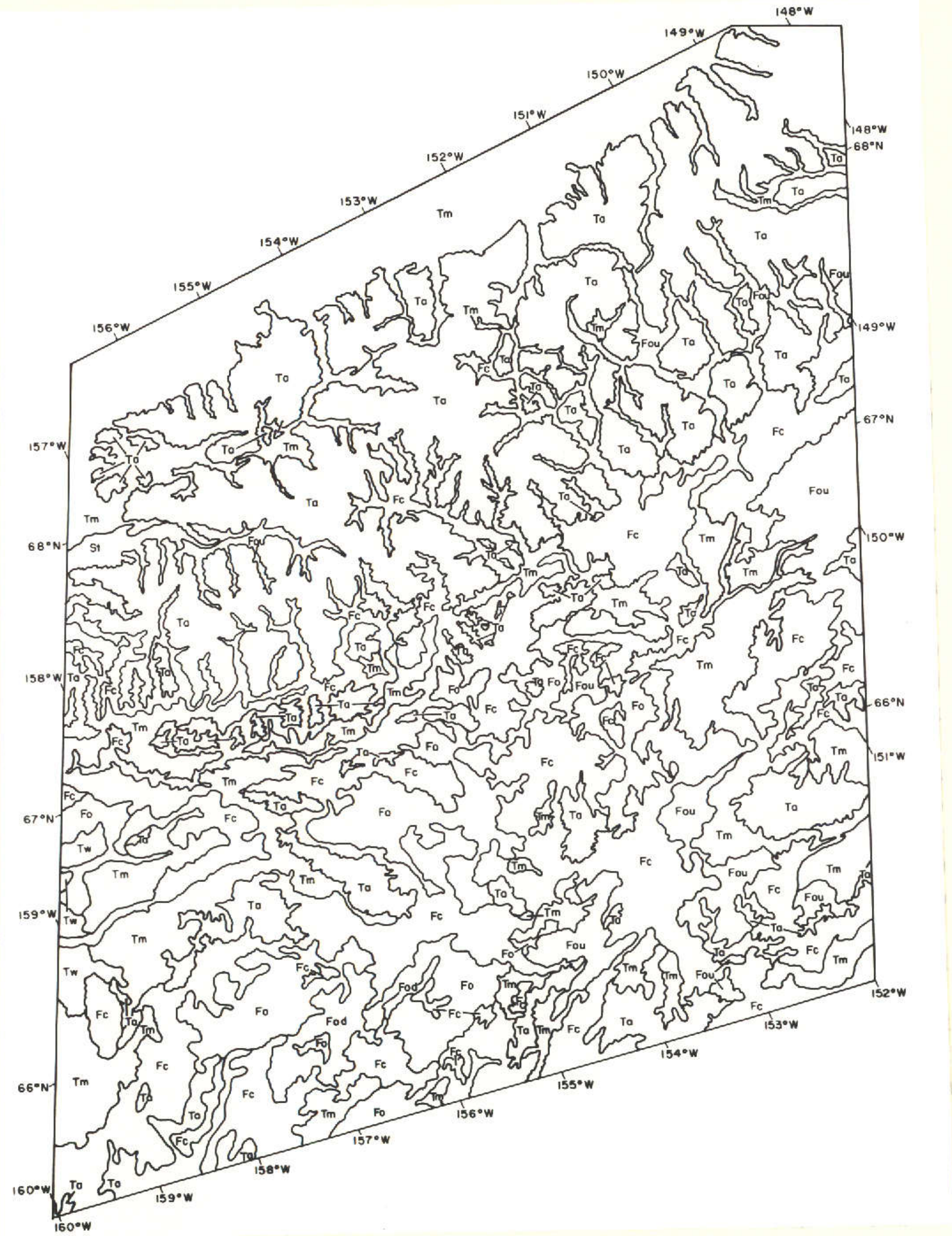


Figure 16. Vegetation of north-central Alaska.

Fc	Closed spruce-hardwood forest	Tm	Moist tundra
Fou	Open spruce-hardwood forest	Tw	Wet tundra
Fo	Open black spruce forest	St	Shrub thickets
Fod	Open black and white spruce forest	Ta	Alpine forest

absent. Wet tundra (Tw) consists of sedge and cottongrass with few woody plants. This association is distinguished from Tm by the presence of many thaw lakes and wet areas. Shrub thickets (St) are dense thickets of alders, willows, blueberries and other woody berry shrubs found in coastal areas and floodplains north of the timberline. Extensive areas of this association in the northern foothills are indicated on existing vegetation maps. However a distinctive pattern is not visible in the ERTS mosaic because of an extensive snow cover. Alpine tundra (Ta) is primarily barren, but locally dominated by low heath shrubs, prostrate willows and dwarf herbs. This association is generally found at elevations over 600 m within the mosaic area.

3.3 Permafrost

Four permafrost terrains, based primarily on the interpretation of surficial geology and the probable depth of thaw inferred from the vegetative cover (Fig. 17), have been mapped. The bedrock (m) terrain in this area is characterized by a few scattered taliks and thaw depths of 0.3-1.0 m, except on south-facing slopes where thaw depths may exceed 2 m. Soils are coarse-textured and shallow. Alpine vegetation occurs in the highest, steepest areas with black spruce and paper birch on the north-facing slopes. The principal trees on south-facing slopes are white spruce, paper birch, quaking aspen and alder. The alluvium-colluvium (u) permafrost terrain contains

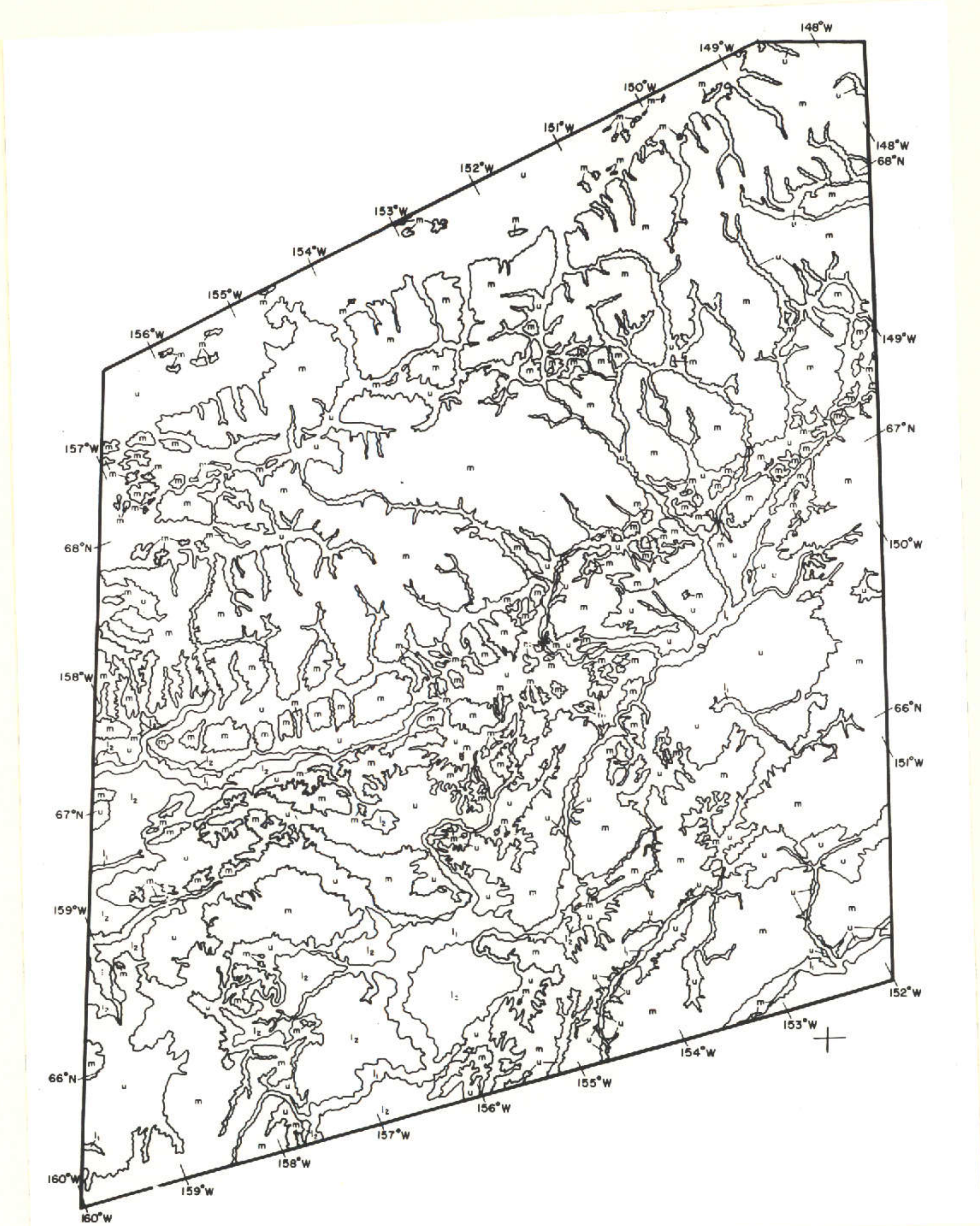


Figure 17. Permafrost terrain map of north-central Alaska.

m	Bedrock	l_1	Active floodplain
u	Alluvium-colluvium	l_2	Abandoned floodplain and terrace

numerous taliks and has thaw depths of <0.5 m in areas of poor drainage and 0.5-2.0 m on moderately to well-drained slopes. Fine-grained, shallow soils occur on steep slopes and medium-to fine-grained, deep soils on gentle slopes. Alpine vegetation occurs on summit positions and black spruce and paper birch on north-facing slopes. White spruce, quaking aspen and alders are found on the south-facing slopes. Moist tundra occurs on poorly drained footslope positions. The active floodplain (l_1) terrain is characterized by numerous taliks, a thaw depth of more than 2.0 m, and fine-grained, deep soils. Balsam poplar, paper birch and white and black spruce dominate. The fourth permafrost terrain unit, abandoned floodplain and terrace (l_2) is characterized by numerous taliks and many small thaw lakes. Soils are fine-grained and shallow with permafrost occurring at depths usually less than 0.5 m. Vegetation includes moss, lichens, low lying shrubs and black spruce.

Using these criteria, a permafrost terrain map has been prepared in considerably greater detail than any previously available. Thus it appears feasible to utilize ERTS-1 imagery, extrapolating from existing vegetative and surficial geology maps and existing "ground truth" to produce improved and more detailed permafrost maps.

4.0 Sediment distribution and coastal processes in Cook Inlet, Alaska

Cook Inlet is a large tidal estuary in south-central Alaska. It is oriented in a northeast-southwest direction and is approximately 330 km long and increases in width from 37 km in the north to 83 km in the south. The inlet is bordered by extensive tidal marshes, lowlands with many lakes, and mountains (Fig. 18, 19). Tidal marshes are prevalent around the mouth of the Susitna River, and in Chickaloon, Trading and Redoubt Bays. The Kenai Lowland separates the inlet from the Kenai Mountains on the upper southeast side. The Susitna Lowland lies between the Talkeetna Mountains on the northeast and the southern Alaska Range on the northwest. The Kenai Mountains are adjacent to the inlet mouth on the southeast; the Alaska-Aleutian Range forms the western border.

Some of these natural features and the major cities, towns and a previously unmapped development south of the mouth of the Drift River are readily identifiable in figure 20. Anchorage (1) is situated between Knik (2) and Turnagain (3) Arms in the northern portion of the inlet. Fire Island (4) is located approximately 5 miles off the coast west of Point Campbell. The Susitna River (5), with an average discharge of approximately 918 m^3/sec (Wagner et al., 1969), is a major contributor of sediment to the inlet. Note the well-defined channels which have formed on the delta at the river mouth. Chaickaloon Bay (6) and other areas around the border of the northern inlet have extensive tidal flats (7). MacArthur River (8), a glacial stream originating in the Chigmit Mountains to the west, drains into the inlet in Trading Bay (9). Trading Bay has 14 oil producing platforms around Middle Ground Shoal and is the major site of active petroleum production in the Cook Inlet area. There is an oil refinery and a tanker

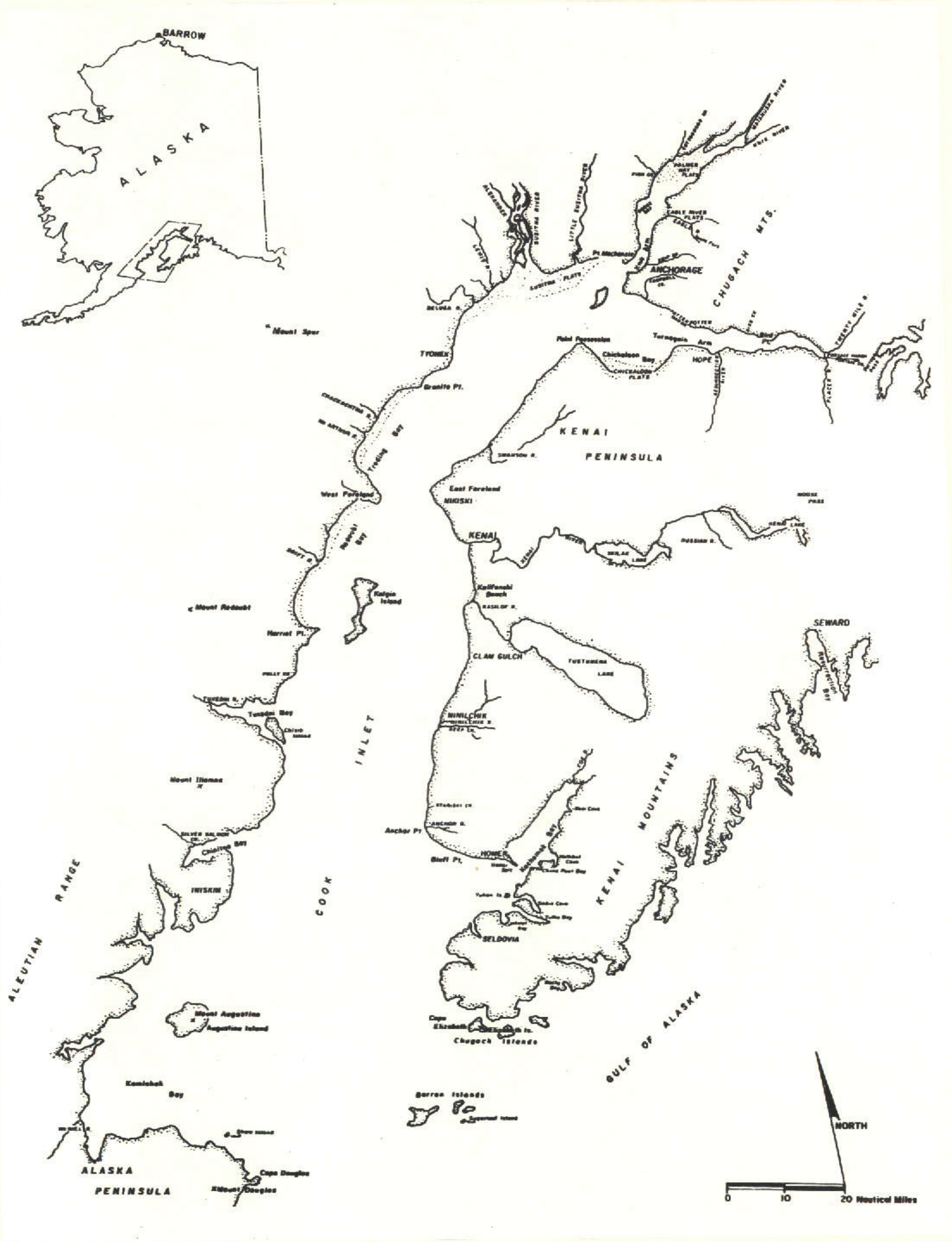


Figure 18. Regional map of Cook Inlet.

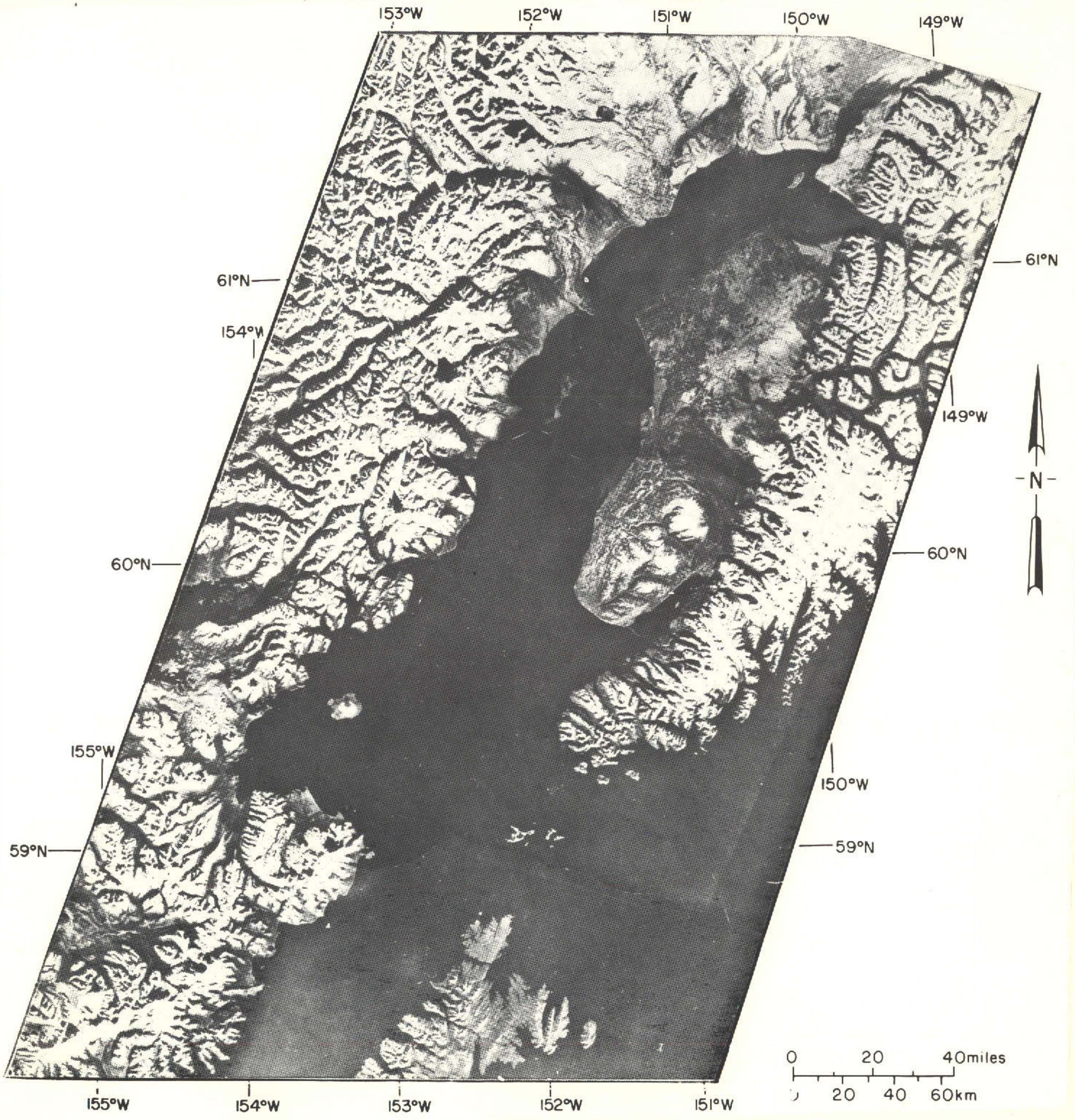


Figure 19. Geographic setting of Cook Inlet. Mosaic made from MSS Band 6, images 1103-20513, 1103-20520, 1103-20522, 1104-20572, 1104-20574, 1104-20581.

Figure 20. Northern portion of the Cook Inlet area. MSS Band 6, image 1103-20513, acquired 3 November 1972.

terminal located in Nikiski (10). Kenai (11), at the mouth of the Kenai River, is a fishing and oil and gas processing center. The Kenai Lowland (12) is a flat, glaciated plain marked by numerous lakes and swampy areas. The Kasilof River (13) begins at Tustumena Lake and discharges into the inlet approximately 21 km northeast of the lake. Kalgin Island (14) is located in the central portion of the inlet and separates the two deep channels found between Harriet Pt. and Kasilof. Near the mouth of the Drift River is a tanker terminal, an oil storage area, and a landing strip (15). Sediment patterns and a tongue of oceanic water (16) with a lower suspended sediment concentration are discernible in the inlet. The higher concentration of sediment elsewhere in the inlet waters is discernible because the sediment laden water produces more reflection of visible light and appears lighter.

The southern portion of Cook Inlet (Fig. 21) is less populated than the northern area but has numerous small towns. Ninilchik (1), Anchor Point (2), Homer (3), and Homer Spit, approximately 5 km long, are located along the southern shore of the inlet. Homer, at the mouth of Kachemak Bay (4), is a fishing town and is often used as a port for ocean vessels caught in foul weather in the Gulf of Alaska. Seldovia (5) and English Bay (6) are small fishing villages on the northern side of the Kenai Range at the inlet mouth. The Chugach Islands (7) are clearly seen on the south side of the Kenai Mountains. The mountainous west shore of the inlet is marked by many varied embayments. Tuxedni (8), Chinitna (9), and Kamishak (11) Bays are

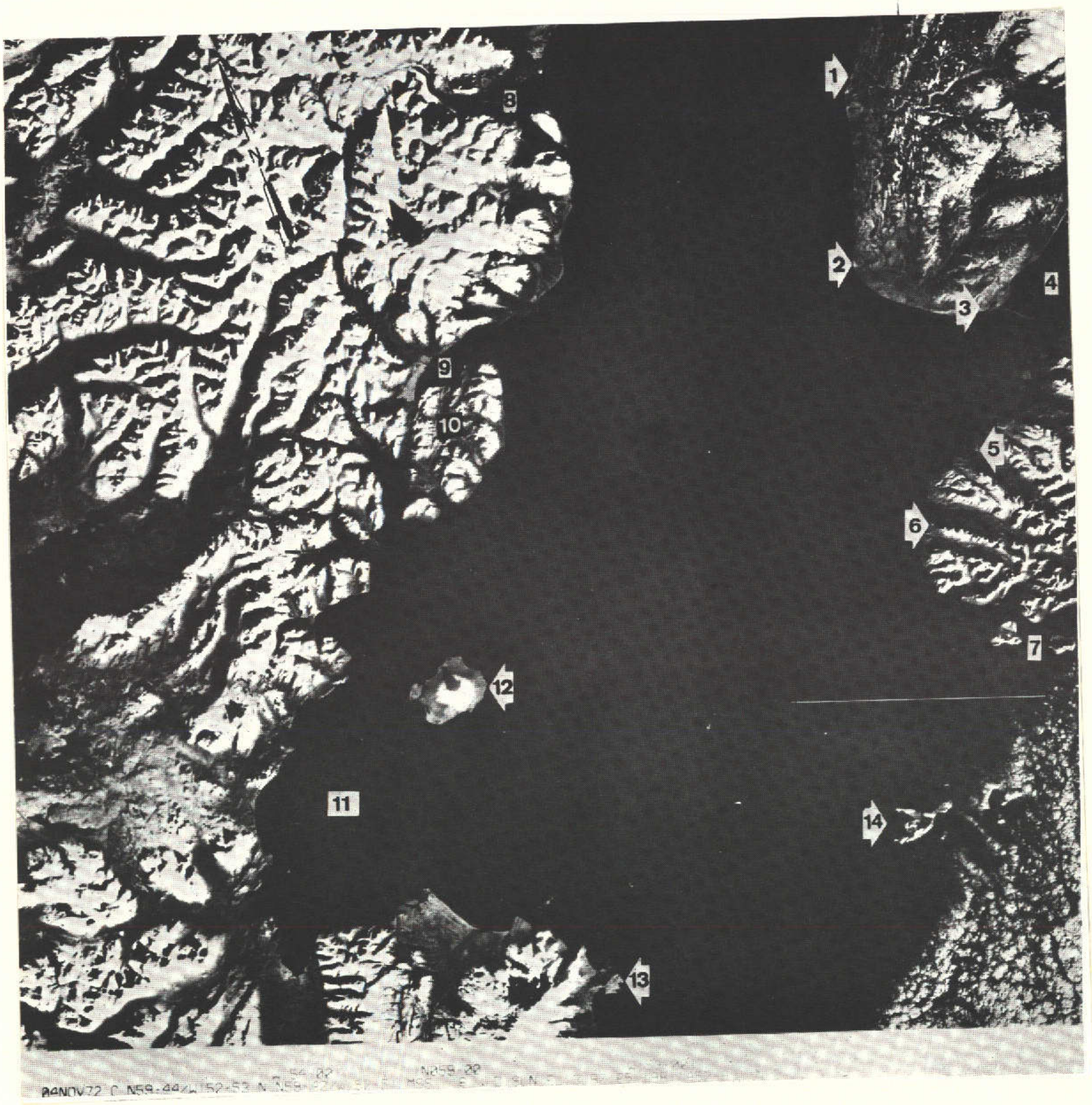


Figure 21. Southern portion of the Cook Inlet area. MSS Band 6, image 1104-20574, acquired 4 November 1972.

the largest along this shoreline. Geologic structure of the Iniskin Peninsula (10) is discernible on the image. Augustine Island (12) is an active composite volcano (stratovolcano) with a classic conical shape. It has a history of violent eruptions typical of an andesitic type volcano (Selkregg et al. 1972). Cape Douglas (13) is located at the western edge of the inlet mouth and between the Barren Islands (14) and the Kenai Peninsula to the north is the Kennedy Entrance to the inlet. The difference in sediment concentration between the oceanic water intruding into the inlet on the east and the inlet water moving out on the west is faintly visible in this image. The water boundary is approximately in the middle of the inlet and runs in a north-south direction.

4.1 Tidal flat distribution

The high sediment load in glacial rivers is the main source of material which has created extensive tidal flats throughout the inlet. MSS band 5 and 7 images are ideal for examination and analysis of certain regional aspects of these tidal flats. Because most of the sediment deposited in the inlet is carried by the Susitna and Knik Rivers (Wagner et al. 1969) the greatest area of tidal flats is in the inlet north of the forelands (Fig. 22). In the lower inlet the tidal flats occur as bayhead bars in the numerous embayments along the western shore and northeast of Homer in Kachemak Bay. The high current velocities and frequent changes in current direction of the inlet water produce variations in the distribution and configuration

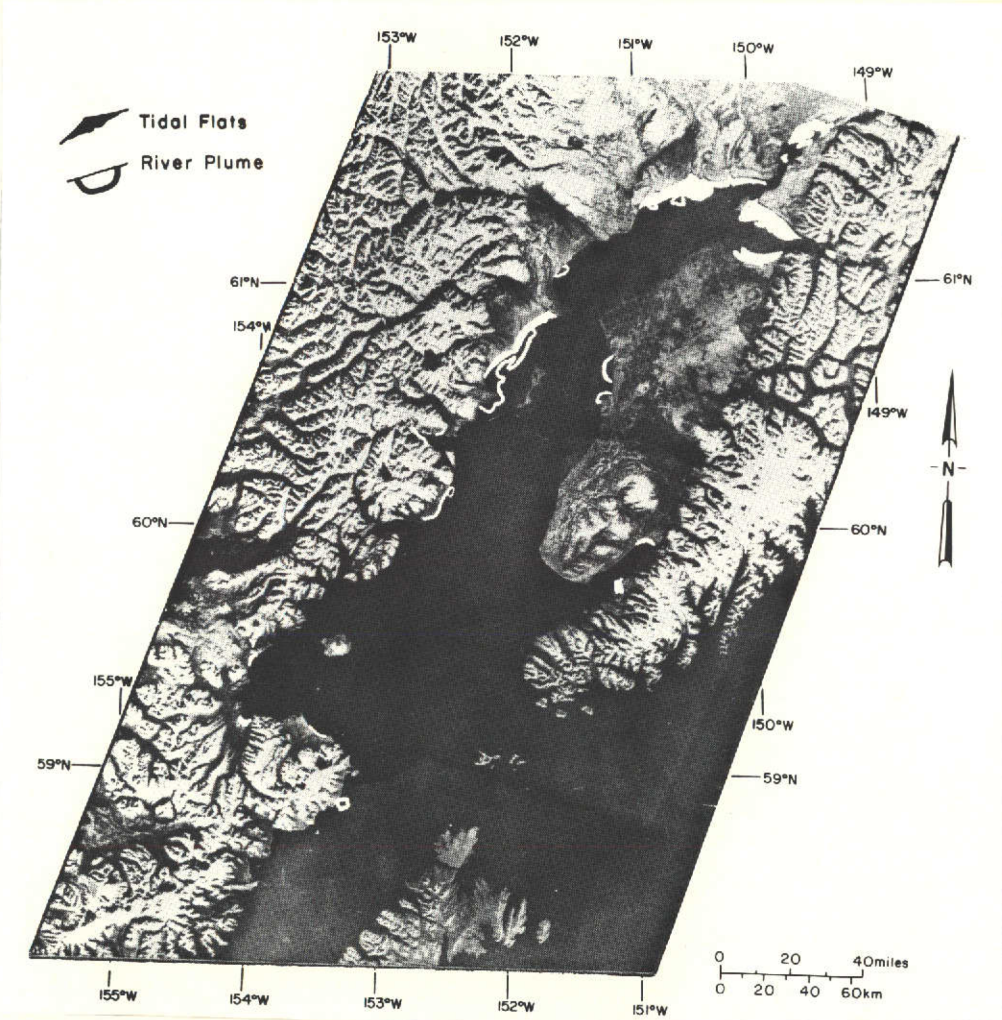


Figure 22. Tidal flat distribution and river plumes.

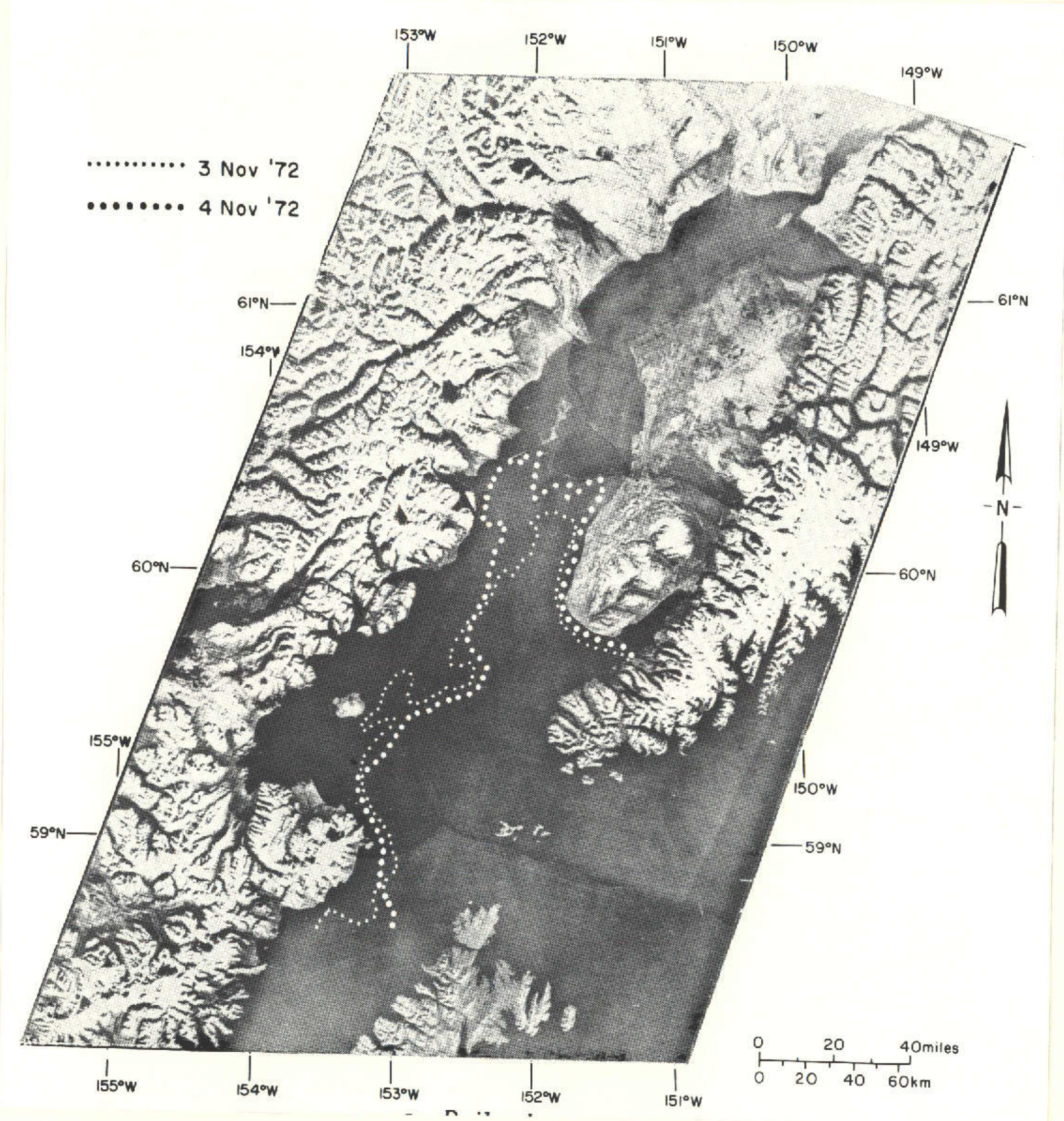
of the flats. The migration of some major tidal flat channels and the redistribution of some tidal flats in Knik and Turnagain Arms can be detected by comparing Figure 20 with National Ocean Survey Navigational Chart 8553. A knowledge of these changes is particularly important in maintaining navigation channels and harbor facilities.

4.2 River plumes

Sediment-laden rivers which discharge into the inlet produce sediment plumes that are visible on MSS bands 4 and 5. Figure 22 shows the distribution of plumes from some of the major rivers entering the inlet. Although the Knik and Matanuska Rivers at the head of Knik Arm contribute most of the sediment deposited in the inlet (Wagner et al. 1969) these rivers do not have distinct sediment plumes. The river-borne sediment is dispersed so quickly in this high energy area and the sediment concentration of the inlet water is so high (approximatley 1350 mg/liter; Kinney et al., 1970) at this location that a distinct plume is not formed. The Susitna River, another major sediment contributor, has only a small plume because the river discharge is reduced during the winter months (Wagner et al. 1969). In addition, the plume is less distinct because the inlet water at the mouth of the Susitna River has a high suspended sediment concentration (approximately 1540 mg/liter; Kinney et al., 1970).

4.3 Water masses

MSS Bands 4 and 5 clearly show the distinction between the more sediment-free, saline, oceanic water in the southeastern portion of the inlet and the sediment-laden, fresher inlet water in the northern and southwestern portions. As noted earlier, recognition of this relationship is possible because the sediment in the inflowing fresh water functions as a tracer, making sediment distribution patterns visible. Daily changes and changes which occur within 18 days in this regional sediment distribution can be detected. Figure 23a shows differences in the main boundary between the oceanic and fresh water in the southern inlet on two successive days. The boundaries separate the water types during low tide in Anchorage and high tide in Seldovia. The irregularity of the western portion of these lines may be due to the upwelling of cold, saline oceanic water in the western portion of the inlet (Kinney et al., 1970; Evans et al., 1972). The northern portion of the 4 November boundary is also quite irregular, possibly due to this upwelling effect. Some estuaries are characterized by a salt wedge that moves headward into the estuary along the bottom while the fresh water outflow moves over this wedge and out the estuary (Bowden, 1967). In Cook Inlet this subsurface tongue of oceanic water progresses headward and moves up the shoaling bottom of the inlet to the latitude of Tuxedni Bay where it rises to the surface south of Kalgin Island during flood tide (Kinney et al., 1970). The upwelling water appears as a large area of clear water surrounded by sediment-laden water. This process produces a zone of high nutrient concentration in the photic zone at this location. This may be significant to the fishing industry since certain species of fish may tend to concentrate in this high nutrient area. Changes in the boundary over an 18-day cycle are shown in Figure 23b. These boundaries are generally comparable to those in Figure 23a. Although changes in the sediment distribution and surface circulation



a. Daily changes.

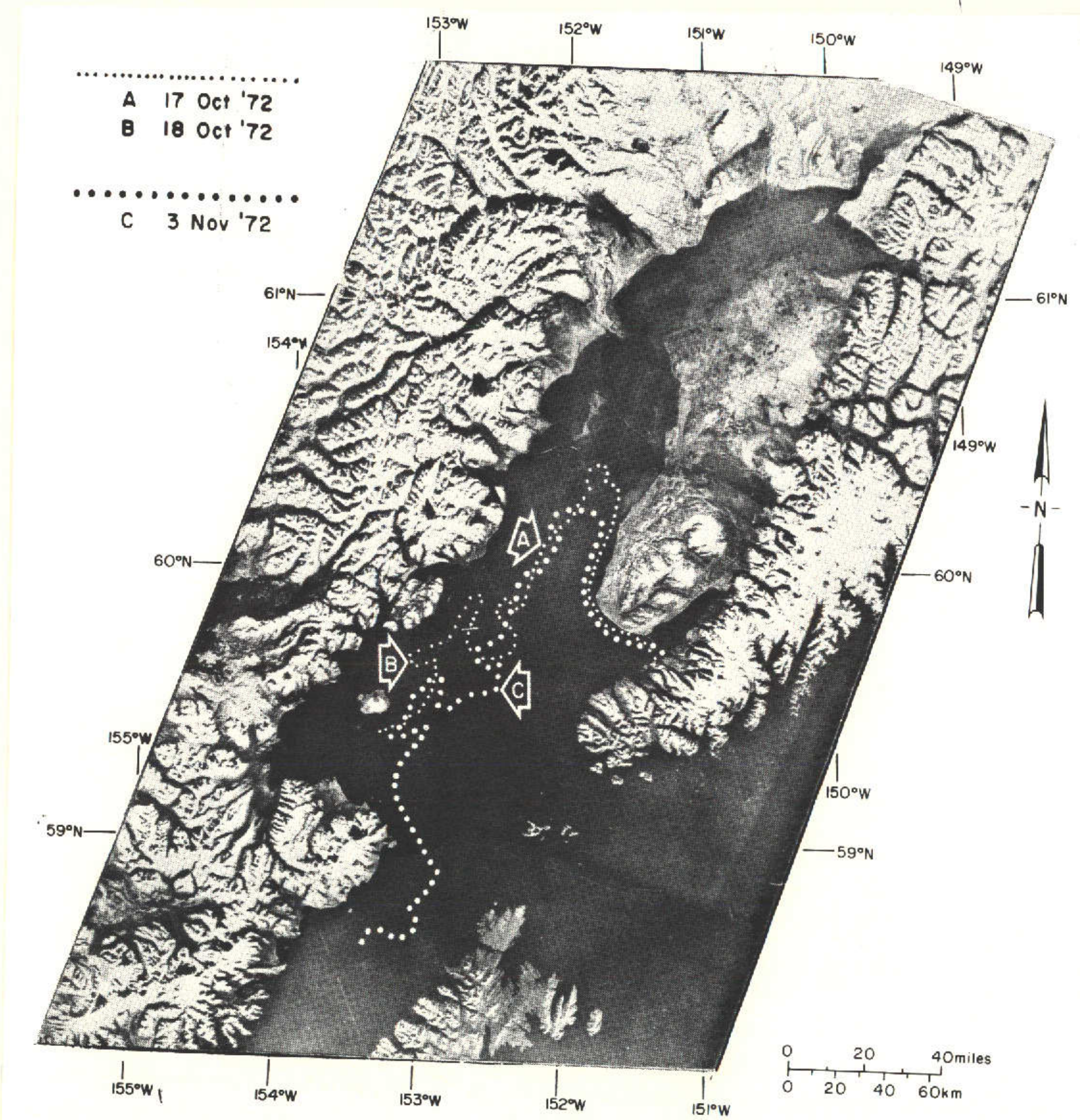
Figure 23. Boundaries separating oceanic and inlet water.

produce some obvious alterations in the regional distribution of water types, the overall relationship of the water types appears to remain consistent with time.

4.4 Surface circulation

The regional circulation patterns within Cook Inlet are controlled primarily by the interaction between the semidiurnal tides, Coriolis force, and the counterclockwise Alaska current. Currents within particular areas are influenced by bathymetry, morphometry and fresh water drainage (Evans et al., 1972). The water in the upper inlet is well mixed due to the large tidal fluctuations in this shallow, narrow basin. During summer, when surface runoff is high, there is a net outward movement of water from the upper inlet. With reduced runoff in the winter there is virtually no net outflow (Murphy and Carlson, 1972). The middle inlet has a net inward circulation of cold, saline oceanic water up the eastern shore and a net outward flow of warmer and fresher inlet water along the western shore (Evans et al., 1972). These water types are well mixed vertically along the eastern shore but separated laterally, resulting in a shear zone. In the lower inlet this lateral temperature and salinity separation is maintained but in the western portion vertical stratification occurs with colder, saline oceanic water underlying warmer, less saline inlet water. During tidal inflow the deeper oceanic water rises to the surface at the latitude of Tuxedni Bay and mixes with the inlet water (Kinney et al., 1970).

The bathymetry in the inlet, another factor in influencing currents, is varied throughout the estuary. The depth of the upper inlet north



b. Changes over 18-day period.

Figure 23 (Cont'd).

of the forelands is generally less than 36 m. The deepest portion, 82 m, is located in Trading Bay just off the mouth of the MacArthur River (Sharma and Burrell, 1970). Turnagain and Knik Arms are the shallowest areas, with much of the bottom exposed as tidal flat. South of the forelands, two channels, one between Kalgin Island and Harriet Point and another between Kalgin Island and the southeast shore, extend southward in the inlet and join in an area west of Cape Ninilchik. The deepest portion of the western channel, located between Kalgin Island and Harriet Point, is approximately 130 m. The eastern channel is deepest, 135 m, just south of a line between the forelands but rapidly shoals to approximately 55 m until it merges with the western branch to form a single channel. South of Cape Ninilchik this channel gradually deepens to approximately 145 m and widens to extend across the mouth of the inlet between Cape Douglas and Cape Elizabeth.

The semi-diurnal tides in Cook Inlet are characterized by two unequal high tides and two unequal low tides per tidal day (24 hours, 50 minutes). Because of the size of the inlet, high tide in Anchorage occurs 4 1/2 hours later than at the inlet mouth (Fig. 24). Mean diurnal tide range varies from 4.2 m at the mouth to 9.0 m at Anchorage. It varies within the lower portion of the inlet from 5.8 m on the east side to 5.1 m on the west side (Wagner et al., 1969). The extreme tidal range produces tidal currents typically 4 knots (2.2 m/sec) and occasionally 6 to 8 knots (Horrer, 1967). The high Coriolis force at this latitude, the strong tidal currents and the inlet geometry produce numerous cross currents and considerable turbulence during both ebb and flood tides (Burrell and Hood, 1967). The turbulence is especially severe along the eastern shore

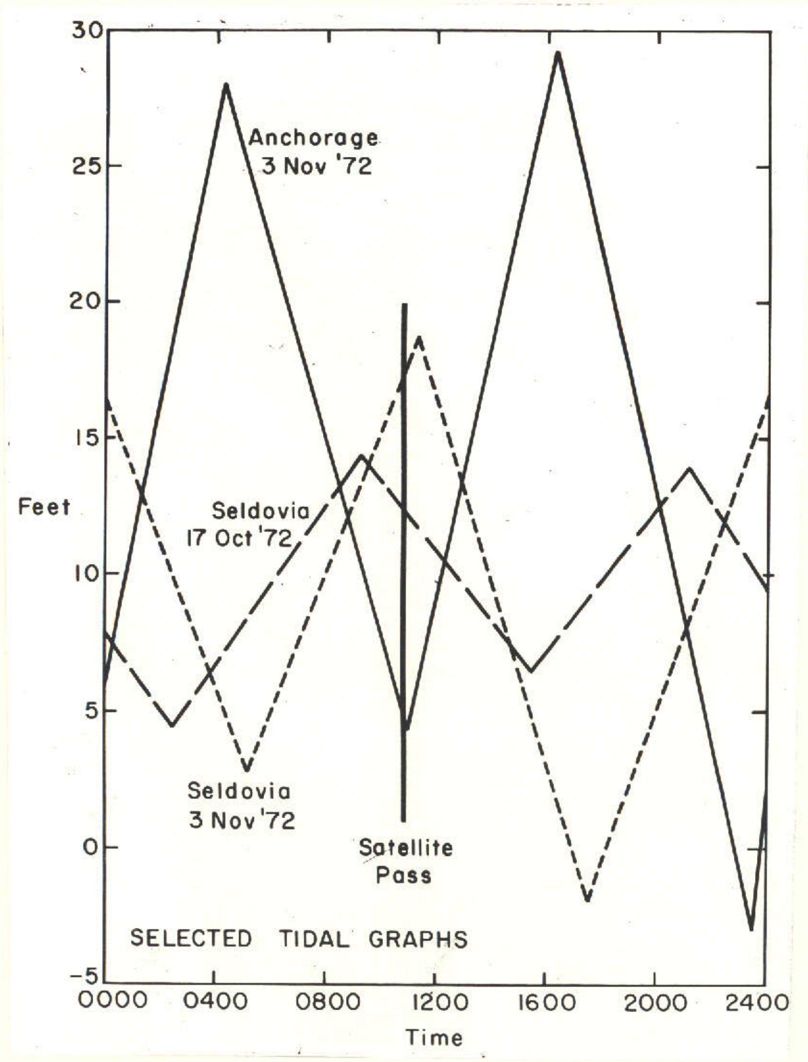


Figure 24. Selected tidal graphs.

of the inlet.

High suspended sediment concentrations in the inflowing fresh water and in the inlet water function as natural coloring agents by which the surface circulation of tidal and long-shore currents can be observed in MSS Bands 4 and 5. Figure 25 shows the surface circulation in the inlet deduced from published data (Evans et al., 1972) and as inferred from ERTS-1 imagery. The regional circulation of the inlet water is understood in general and was observed and verified with few exceptions in the ERTS imagery. The clear oceanic water enters the inlet at flood tide along the east side around the Barren Islands. A portion of this clear water is forced into the inlet by the counterclockwise Alaska Current in the Gulf of Alaska. A tongue of this oceanic water (Fig. 23) occupies the southeastern portion of the inlet and becomes less distinct in a northeast direction by mixing with the sediment in the upper inlet water around Ninilchik. The tide front progresses from the mouth of the inlet to Anchorage in approximately 4 1/2 hours. It moves faster along the east shore, being diverted in that direction by the Coriolis force. A back eddy not previously reported (dotted arrows) was apparent on MSS frames 1103-20513-5, 1103-20520-5 and 1104-20574-5 just offshore from Clam Gulch. The eddy forms in the slack water area northeast of Cape Ninilchik during flood tide.

The tide front continues past the East Foreland, a large peninsula protruding some 10 miles into the inlet, and is partially diverted across the inlet, where it abuts the West Foreland. At this point, part of the diverted front moves south of the West Foreland and the remainder moves north. This circulation pattern is repeated twice daily during the two daily flood tides. The result is a counterclockwise circulation pattern

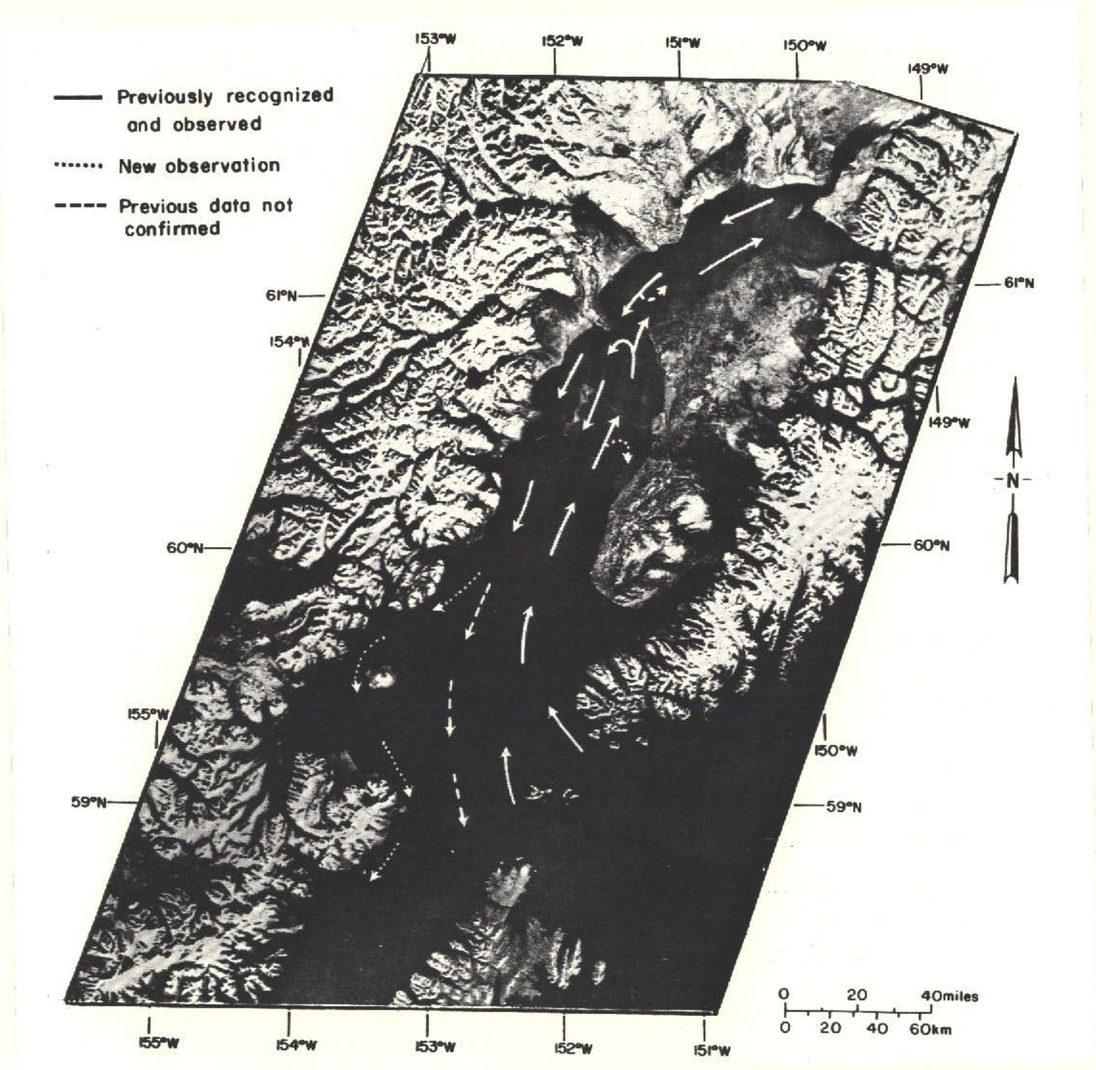


Figure 25. Surface current patterns. Patterns were visible on MSS Bands 4 and 5, images 1103-20513, 1103-20520, 1103-20522, 1104-20572, 1104-20574, 1104-20581.

around Kalgin Island . This pattern was verified by direct observation from an altitude of 1800 m at the time of satellite overpass. The circulation of surface water north of the forelands appears to be similar to that previously reported (Evans et al., 1972). The ebb flow in the inlet moves predominantly along the northeastern shore past the forelands. This pattern was discernible on the imagery except for a previously reported counterclockwise pattern (dashed arrow) north of the forelands. This pattern is formed as the ebbing waters abut the West Foreland and some are diverted across the inlet and move headward with the flood current along the east shore. As the sediment-laden ebbing water moves past the area of Chinitna Bay it appears to flow along the shoreline and circulate around the west side of Augustine Island in Kamishak Bay. It continues to parallel the coast past Cape Douglas and progresses through Shelikof Strait. This circulation pattern in Kamishak Bay west of Augustine Island was not previously reported but is clearly visible on the MSS imagery.

The currents and circulation patterns are especially important in determining the distribution of suspended and bottom sediments throughout the inlet. The suspended sediment is mostly of glacial origin with the highest concentrations in the northern portion of the inlet, a well-mixed turbulent zone of strong tidal currents. Suspended sediment is nearly absent in the waters of the central and eastern portions at the inlet mouth. Bottom sediments have been grouped into three facies: a facies composed predominantly of sand in the upper inlet, a facies composed of sandy gravel with minor silt and clay in the middle inlet, and a facies composed of gravelly sand and minor interspersed silt and clay in the lower inlet (Sharma and Burrell, 1970).

5.0 Martian terrain analogs

The resolution of the ERTS multispectral scanner and Mariner 9, Camera B, imagery is comparable. Therefore martian permafrost features similar in appearance and size to terrestrial permafrost features resolved by ERTS might be expected to be resolved on the Mariner 9, B-frames. Prior to the launch of both Mariner 9 and ERTS-1 it was thought that patterned ground, exceptionally large pingos, and large-scale thermokarst depressions would be the permafrost features most likely to be detected. Several ERTS-1 scenes of Alaska show terrestrial permafrost terrain features large enough to be seen if present on the Mariner B-images.

MSS image 1058-2142, of the south coast of Norton Sound, shows patterned ground in the swampy lowland of the Yukon River Delta. Normally, ice-wedge polygons are less than 100 m across and would be too small to be detected by either satellite. The distinct polygonal patterns in this scene, however, are approximately 300-500 m across. They occur in a region generally underlain by moderately thick to thin permafrost, and their unusually large size is quite remarkable. U. S. Navy aerial imagery (Fig. 26) of this area has been obtained which permits an interpretation. It shows that these patterns result from the alignment of old beach ridges (1) and the orientation of old distributary channels (2) and thaw lakes (3) (Shepard and Wanless, 1971). A superficial comparison can be made to the polygonal patterns on Mars shown in Mariner 71 image number PLYBK P177, picture 35B. Although the process of formation for the polygonal pattern on Mars is not definitely known it may be related to the presence of ice-rich permafrost there.

Large areas with many thaw lakes and thermokarst depressions have been identified on several snow enhanced ERTS images of the Alaskan North Slope. Some of the thaw lakes in this area have coalesced to form a topography similar in appearance to the alas topography of Yakutsk, Siberia, described by Czudek and Demek (1970). These regions bear considerable resemblance to the chaotic terrain of Mars revealed in the Mariner 9 B-frames.

Pingos are generally too small to be detected on the ERTS imagery; however, when the location of a pingo field is known, tones and textures which suggest its presence can generally be distinguished on close inspection. These indications are visible in the areas on figure 13 where pingos have been identified by ground and aerial observations. Unless analogous features present on Mars are very much larger, they would be too small for positive identification on the Mariner imagery.

Aquisition of the additional satellite imagery will supply the extended coverage required to better understand the distribution and major patterns of the geomorphic indicators of permafrost. New information on permafrost and its related features, such as the scale of permafrost features, their distribution, and the environment necessary for their formation, is expected and will be subjected to similar analysis and comparison.

6.0 Correlation between snowpack and runoff in the Caribou-Poker Creek watershed

Tonal and textural variations of the snow cover apparent on the ERTS imagery are being correlated with snow accumulation, depth and ablation in the Caribou-Poker Creeks watershed. Snow conditions are being monitored and related to runoff. Measurements of the depth and distribution of the snowpack in the entire watershed were made (by extensive snow surveys)

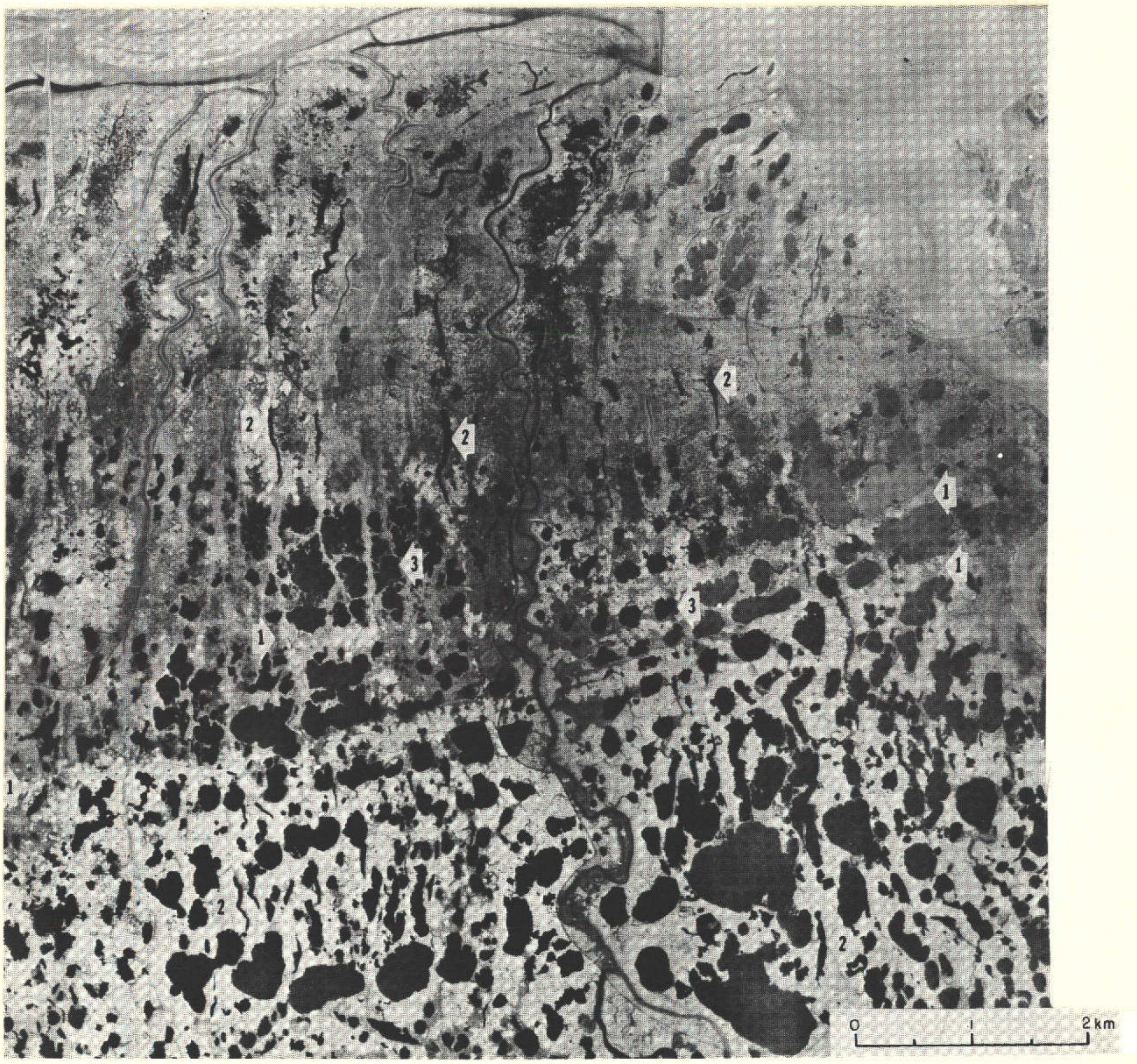


Figure 26. Photo mosaic of aerial photographs of the southern coast of Norton Sound.

prior to runoff. The distribution of snow in early November is apparent on MSS frames 1103-20402, 1103-20504, 1104-20560, and 1104-20563, but all subsequent images of this region have too much cloud cover to be usable for this phase of the investigation.

7.0 Icings on the Chena River

Preliminary mapping of the Chena watershed was accomplished on MSS scene 1103-20502. Corroborative underflight imagery taken on Mission 209 in July 1972 of the Chena River channel has been reviewed. Ground and aerial surveys of the main channel of the Chena River were made in March, 1973. Color photographs were taken to document the size and location of icings. Numerous small icings were located and photographed on the upper Chena and its tributaries during March and April, 1973, but they did not persist long enough after breakup to be located on ERTS imagery. Although several large icings were located with ERTS imagery on Alaska's north slope, the winter and spring of 1973 was not conducive to the formation of sizeable icings in the interior. The utility of ERTS imagery for surveying and monitoring icings on the north slope has been demonstrated in preliminary work. The techniques being developed to monitor icings on ERTS imagery can be used to recommend and perform the appropriate corrective action to reduce or eliminate the adverse effects of icings on the one hand, or to possibly exploit their presence, on the other.

8.0 New Technology

No new technology has been developed during this reporting period.

9.0 Program for the next reporting interval

The analysis and mapping of the sediment deposition in harbors, inlets, and docking facilities in Cook Inlet will continue. Surficial geology, vegetation and permafrost terrain maps will be completed for an extended test area. Phenological events that occurred during the spring and fall, 1973, will be monitored with available imagery. Major tonal and textural permafrost patterns on the Alaskan North Slope and in Yakutsk, Siberia will be compared to similar terrain apparent on the Mariner imagery. The snow cover surveys of the Caribou-Poker Creek watershed will be correlated with stream runoff data acquired this spring. Imagery obtained this spring will be correlated to these data. The utility of ERTS imagery in monitoring and quantifying sea ice movement and deformation will be illustrated on sequential imagery of the Beaufort Sea. The daily rate of ice migration will be calculated for the largest floes. Preliminary analysis will be initiated to determine the use of the photo densitometer in calculating the rate of ice melt on major rivers on the Alaskan North Slope. No departure from the approved Data Analysis Plan will be required for the remainder of this investigation.

10.0 Summary and Conclusions

The 70 meter resolution of ERTS-1 MSS imagery makes possible the identification of many physiognomic landscape features which were used as geologic and vegetative indicators in preparation of a surficial geology, vegetation, and permafrost map at a scale of 1:1 million from the Band 7 imagery. Seven surficial geology units, eight vegetative units and four permafrost terrain units were delineated in 153,400 km^2 of the Kobuk-Koyukuk-Yukon area of north-central Alaska. The detail available from ERTS-1 imagery at 1:1 million scale compared favorably with the detail available on U.S. Geological Survey Miscellaneous Geologic Investigation Maps 290, 437, 459, and 554 at a scale of 1:250,000. Physical boundaries mapped from ERTS-1 imagery in combination with ground truth obtained from existing small scale maps and other sources resulted in improved and more detailed mapping of permafrost terrain and vegetation for this area Applications for and limitations of these analysis are shown in table III.

Prior oceanographic investigations have been undertaken at a number of specific sites in the Cook Inlet area by various governmental and private agencies. ERTS-1 imagery provides, for the first time, a means of monitoring regional estuarine processes. Daily and periodic observations of surface water circulation indicate that a tongue of clear, ocean water moves into the inlet along the east shore to the approximate location of Ninilchik. In this area extensive mixing occurs between the sediment-laden inlet water and the tongue of clear water. Silty inlet water occurs in the western portion of the inlet and generally moves south along the shore towards the inlet mouth. Changes in the relative sediment load of these water masses and of rivers discharging into the inlet can be inferred from the tonal variations between successive cycles. In addition several local patterns not recognized before have been identified. A clockwise back eddy was observed during flood tide in the slack water area between Cape Ninilchick and Kenai offshore from Clam Gulch. A counter-clockwise current forms north of the Forelands during ebb tide. Sediment-laden, ebbing water progresses west of Augustine Island and moves out the inlet past Cape Douglas and through Shelilof Strait.

Comparison of ERTS-1 and Mariner imagery have revealed that the thermokarst depressions found on the Alaskan North Slope are possible analogs to the chaotic terrain on Mars. Also the polygonal pattern identified on the Yukon River delta compares in size to polygonal patterns which occur on the Martian surface.

11.0 Recommendations

None

TABLE III

Limitations* and Applications for ERTS Imagery

	Applications	Limitations
Permafrost Mapping	A. route/site selection B. regional environmental interpretation C. identification and inventory natural resources D. urban and land use planning E. land use regulation and management	A. Criteria not obtainable 1. air & land temperature 2. depth B. Feature not identifiable 1. pingos (palsas) 2. ice wedge polygons 3. solifluction lobes 4. nivation terraces 5. stone polygons and stripes
Sediment Deposition in Cook Inlet	A. Data Base 1. Preliminary site selection 2. Coastal Zone Management decisions B. Augment preparation and revision of hydrographic and navigation charts C. Monitor estuarine circulation 1. Dispersion of pollutants 2. Movement of sea ice D. Fisheries	A. Thermal patterns not visible B. Only circulation patterns with suspended material, floating debris, or sea ice are visible C. Small scale changes (70m) in circulation, tidal flats and coastal landforms are not detectable
Stream Icings	A. Route selection B. Potential fresh water source	A. Resolution of imagery B. Contrast

*General Limitations:
1. Atmospheric attenuation reduces tonal and textural contrast
2. Cloud cover obscures all features
3. Snow cover obscures some small scale topographic features, low-lying vegetation and decreases accuracy of slope determinations

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